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IRON AND STEEL ENGINEER

M A Y • 1939

VOL. XVI NO. V

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Published Monthly by

ASSOCIATION OF IRON AND STEEL ENGINEERS

Entered as second-class matter January 25th, 1924, at Pittsburgh, Pa., under the Act of March 3rd, 1879.

Statements and opinions given in articles and papers appearing in "Iron and Steel Engineer" are the expressions of contributors, for which the Association of Iron and Steel Engineers assumes no responsibility.

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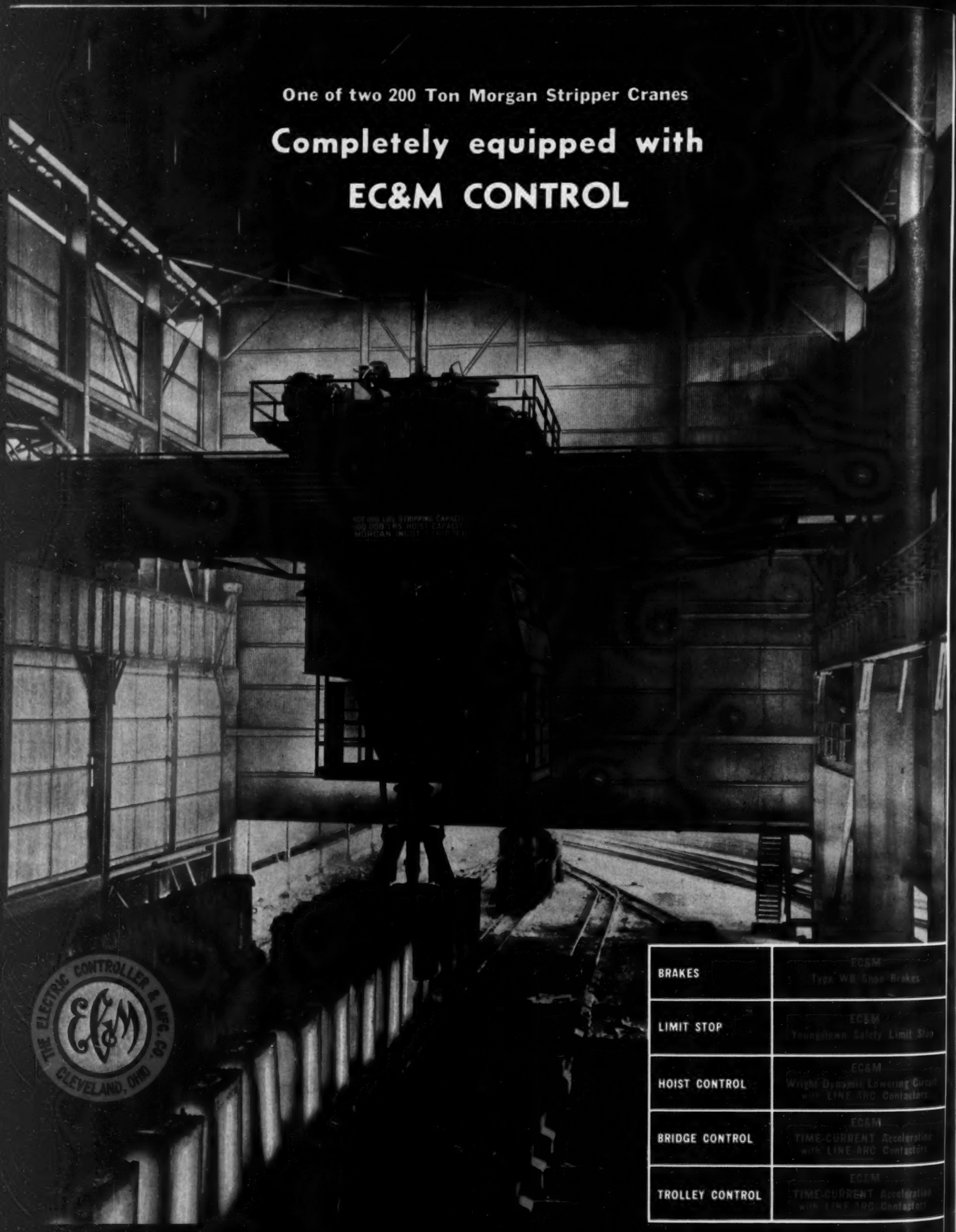

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EVOLUTION *of* WORM GEARING CULMINATING *in the Cone* DESIGN

By G. R. SCOTT, Gear Consultant

Michigan Tool Company

DETROIT, MICHIGAN

Presented before A. I. & S. E.
Detroit District Section
January 10, 1939

▲ WORM gearing has been defined as "a cylindrical or conical piece of wood or metal, having a groove running spirally round it".

The demand for worm gearing originally arose to meet conditions where a large reduction in speed, between the driver and the driven member, was desired in one step; and also where right-angle drives were essential.

Worm gearing is here divided into three classes or types, (Figure 1) as follows:

1—Those having neither element throated.

2—Those having one element throated.

3—Those having both elements throated.

EARLY HISTORY

The first type, wherein neither element is throated, is of great antiquity, extending back to the pre-Christian era. Archimedes is frequently given credit for having invented the earliest form of worm gearing, in which an Archimedian spiral was employed to rotate a toothed wheel.

A number of designs, engraved on wood, by the German artist, Albrecht Durer, (1471-1528), showing worm gears are still in existence. One of these designs shows a four-wheel, worm-driven car.

Mr. Otto Lundell, president of our company, on a recent trip to Sweden discovered a very ancient gear, made of stone, which apparently had operated with a

FIGURE 1—Diagrams of three classes of worm gearing, showing non-throated, single-throated, and double-throated types.

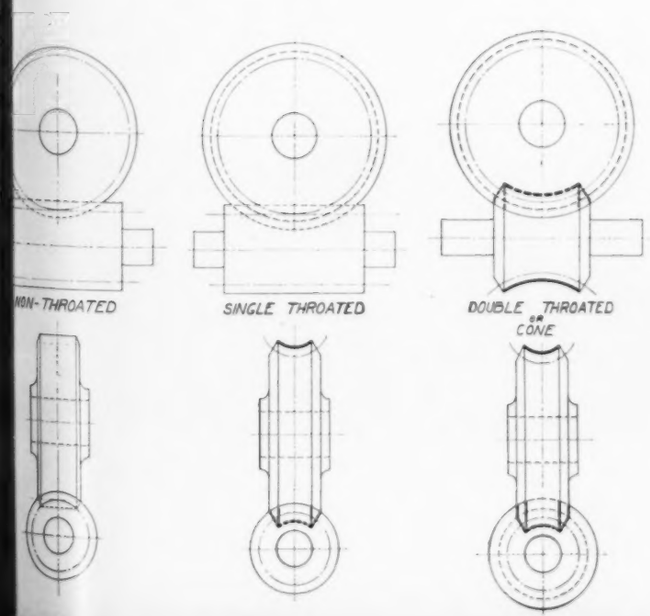
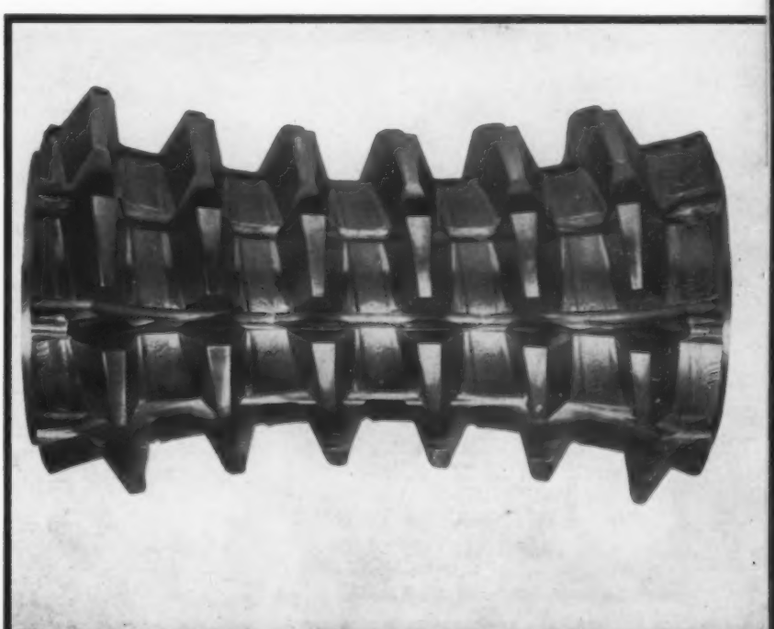


FIGURE 2—A hob is used, identical with the worm as to mating capacity, but having thinner thread flanks.



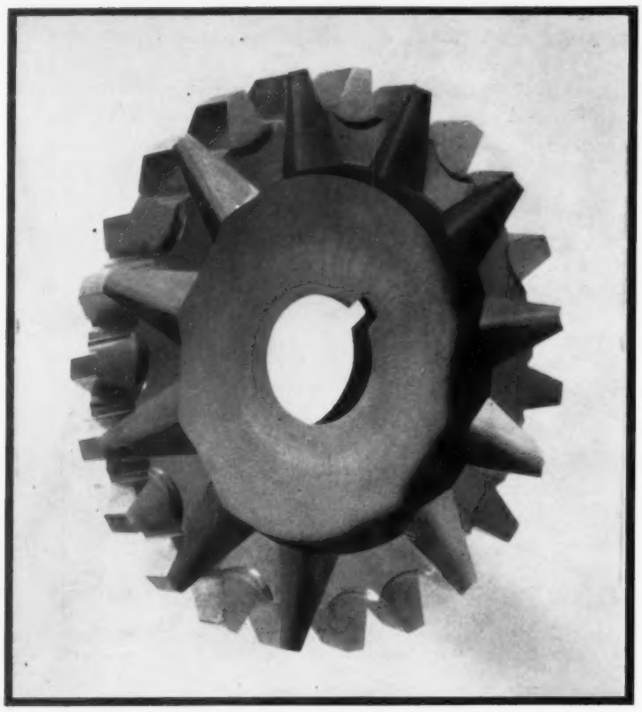


FIGURE 3—The worm is generated by the use of a cutter representing the mid-plane section of the gear.

worm made of wood, the combination being used for the purpose of grinding grain, some eight or nine centuries ago.

The origin of the second type is not known. As early as 1873, however, Hughes and Phillips made successful conventional gearing in this country. The marked progress, however, occurred around 1911, in connection with the application of worm gearing to automotive drives.

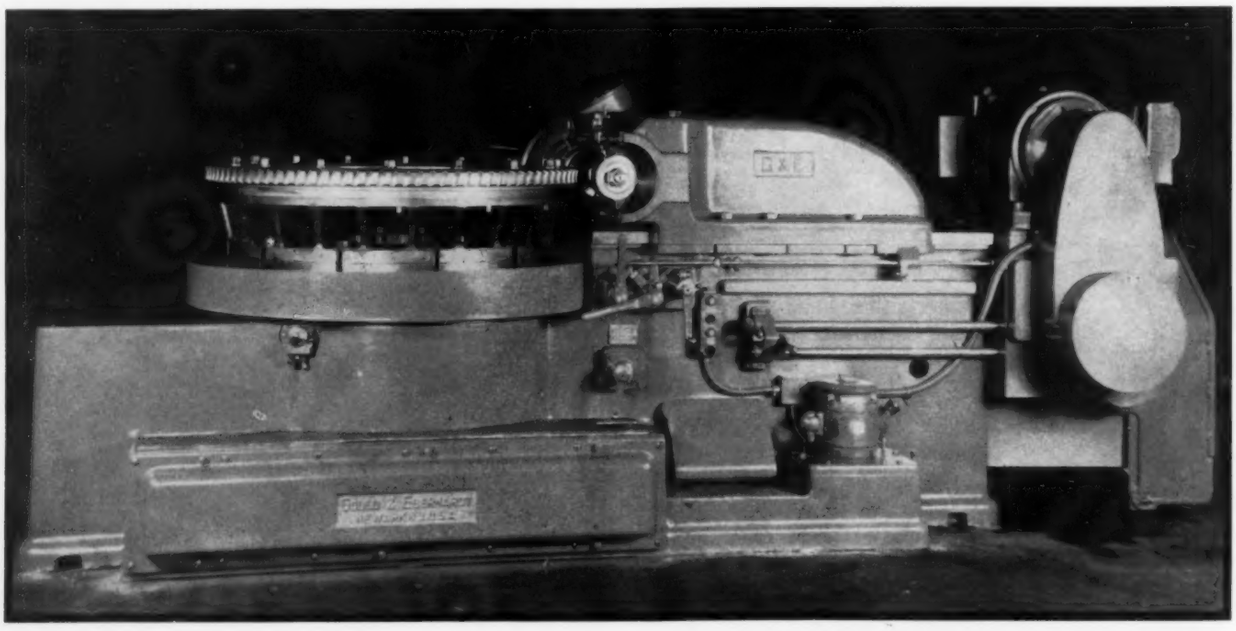
Referring now to the third type, the records show that 200 years ago in York, England, the famous clockmaker, Henry Hindley, made the first throated worm. It was used in a dividing engine, which he is also given the credit of having originated. The gear was 13 in. in diameter and had 360 teeth. The teeth were about 1/16 in. in size and the helix angle employed was only about 1 degree. John Smeatson, a contemporary, says in part as follows: "The threads of this screw were not formed upon a cylindrical surface, but upon a solid, whose sides were terminated by arches of circles—the screw and wheel, being ground together as an optic glass to its tool, produced that degree of smoothness in its motion that I observed, and lastly, that the wheel was cut from the dividing plate".

It is certain, from the above, that the worm was throated, but it is not clear whether the wheel was also throated. The records seem to indicate that it was not.

No further progress was apparently made, with throated worms, until 1878, when Steven A. Morse in this country, became interested in a patent on a machine for cutting them. About 1883, the U. S. Government Engineers became interested in a Hindley type gear, and began using them where heavy shock loads were encountered, and where the absence of backlash was essential.

About 15 years ago, Mr. Samuel I. Cone of Portsmouth, Virginia, manufactured at the Norfolk Navy Yard the first Cone type of worm gear. It is believed that this was the first instance in which "double throated" of "double enveloping" worm gears, having area contact, were ever made.

FIGURE 4—One stage in the development of equipment for production of cone gears was the building of two-spindle, hand-operated machines.



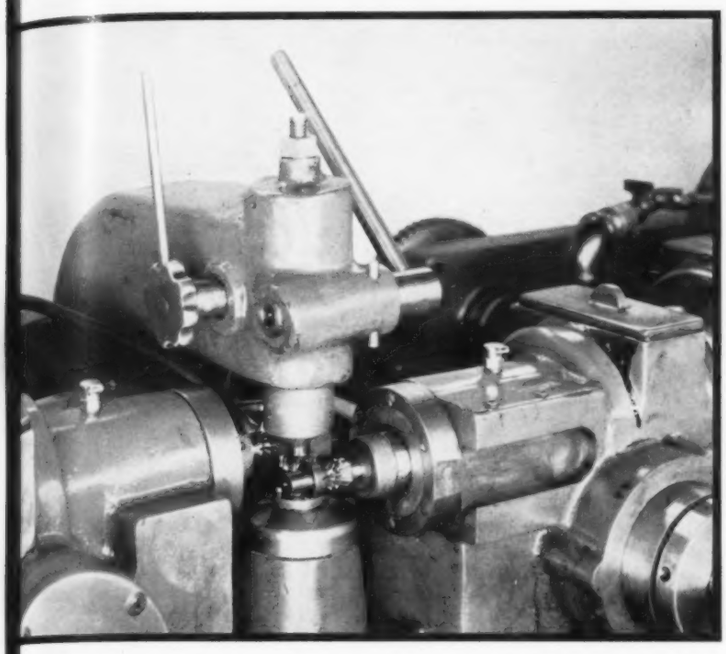


FIGURE 5—The first high production, fully automatic equipment was produced in connection with very small size gears.

EVOLUTION OF WORM GEARING

Although it was only a logical step from the better known spur and helical type of gearing, to the right angle spiral or worm gear, the latter, as manufactured and used up to about the end of the 19th century, was very poorly thought of by gear engineers, as a whole. On the other hand, spur gearing has been highly thought of for many years. The rolling type of contact is believed to be the principal reason. With spur and helical gearing, inaccuracies in form, selection of helix angle, types of material and lubricants used, do not have the same importance that they do in connection with worm gearing, where the contact is largely one of sliding.

The evolution of the present-day non-throated type of worm gear has involved mainly the development of more suitable materials, coupled with the development of better equipment for manufacturing it.

With the more widely used conventional worm gearing, having one element throated, the development history has been, in general, as follows:

(1) The early designers of the conventional worm gear did not realize that its efficiency depended to a very large extent, upon the helix angle of the worm. The first record found of this discovery, is in connection with an exhibit at the Newark Industrial Exhibition in 1873, when Hughes and Phillips' Iron Works exhibited two worm gear speed reducers. One of the gear sets, having a relatively small helix angle, was referred to as "unsuccessful", and the other set, with a moderately large helix angle, was referred to as "successful".

(2) The discovery, by Reniecker, of a means of generating the throated gear element on operating centers by means of a tangential feed, greatly improved the tooth contact.

(3) Some advantage is claimed for a tooth form discovery, made in England, and generally referred to as the David Brown "FJ" type. This type differs from the ordinary worm, in that the thread profile is not straight sided in the axial section, as is the case with the more usual design. This type is considered easier to manufacture, insofar as the worm element is concerned.

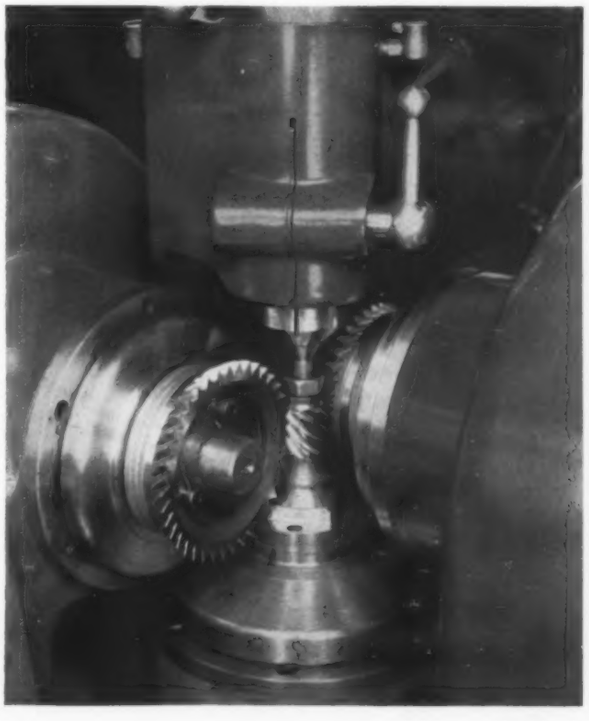
(4) The selection of better materials, coupled with the development of equipment for producing a greater degree of accuracy in the gear sets, also had a profound effect upon making worm gearing more popular with industry.

In connection with the evolution of the double throated or double enveloping type of gear, starting with the throating of the worm by Hindley, 200 years ago, no progress was shown until about 1870. At that date, progress was started in connection with conventional worm gearing.

The type of Hindley gear utilized in this country, incorporated a worm having an enveloping form, and having straight sides in the axis of the worm. It early became apparent, that as a result of the changing diameters and helix angles of the worm, throughout its length, that it would be necessary to utilize a hob in connection with the production of the throated gear element.

The form of the worm itself prevented the use of a tangential feed—utilized in connection with conventional cylindrical gearing—and, therefore, it appeared

FIGURE 6—The latest advance has been the development of larger machines, capable of cutting up to 4 in. center distance.



to the manufacturers of this early type of gearing, that only the radial feed method was available.

In cutting the gears therefore, the universal practice was to feed toward each other, in a radial direction, the hob and a solid gear blank—geared in the proper time relation and rotating on centers. It will be apparent, that for the same reason that the completed elements will not operate satisfactorily on other than the designed center distance, that it was equally impossible to cut the true form by radially feeding the hob and blank together. The method tended to destroy the gear element, the end teeth of the hob being the greatest offenders. In order to minimize this difficulty, the worms were usually made very short, when compared to the available length; thereby reducing the number of teeth in simultaneous contact. Another modification generally made, was to turn the worm and hob on the outside diameter, in such a way as to give it a cylindrical form; thereby reducing the amount of interference, but at the same time, still further limiting the available contact.

Another modification had to do with reducing the width of the gear element.

Having made the above-mentioned modifications, the gear set was cut and subsequently mounted in heavy duty lapping machines, where the elements were ground together for extremely long periods of time. (In most cases, forty-eight hours, with sand and water.) Later, different and more improved types of lapping compounds were utilized.

It is a well-known principle of lapping that the amount of stock which can satisfactorily be removed is limited to a few thousandths of an inch. It is further generally agreed that, to produce satisfactory lapping, one element must first be accurately produced and used as a master, in order to correct any inequalities in the other member. In the process described above, both elements were incorrectly made and consequently, the lapping process utilized, never produced gearing having accurate mating capacity.

This method also tended to lap holes or flat spots in the elements, and consequently, made it necessary not only to replace both elements in the event that one was destroyed, but also the elements had to be assembled in exactly the same position in which they were lapped. It is believed that this condition, more than any other, created the universal impression that the Hindley type of worm gear would tend to lock itself unless it was assembled with extreme accuracy.

The manufacturers of this type of gearing, prior to the Cone development, had found no means of generating "relief", nor of grinding the hobs. Consequently, it was necessary to "relieve" the hob teeth back of the cutting edges by hand filing operations, and distortions that took place during heat treatment could not be removed. As a rule, no attempt was made to resharpen such a hob, as only the cutting edges approached the desired tooth form.

It will be understood that, in producing the Hindley type of gear, both in this country and abroad, no method nor means were found, whereby the classical forms, without modification, could be made. In addition to the modifications that were made, the English manufacturers also introduced an involute form of thread, as against the classical straight-sided form. In this country, the final form, (even after utilizing the modifications mentioned above), was obtained by extensive hand-scraping and lapping.

Referring only briefly to the question of proper design, the outstanding fact is that the relation of the base circle to the permissible length of hob and worm, was not understood.

The records of the patent office disclose that many unsuccessful attempts were made to find methods and means of producing the area contact worm gear. Failure to solve this problem, accounts for the universal practice of modifying the classical form, in order to provide gearing that could be produced. The modifications largely destroyed the inherent advantage to be found in the double throated type. Such gearing had therefore, largely disappeared from use in industry in this country, when the Cone inventions again revived interest in it.

Mr. Cone evolved a rational method and means for generating the elements of Cone gearing, which permit

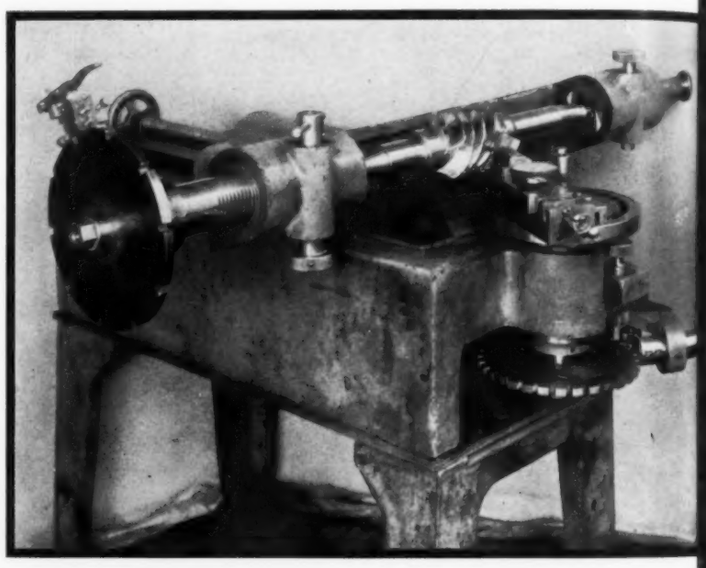


FIGURE 7—Machines have been developed for checking the lead, pressure angle, and spacing of the hob and worm.

the cutting of both elements without interference of any character. The nature of the contact is such, that, in the passage of the worm through the worm wheel, during one convolution, every portion of the worm thread and tooth flank is in contact. For a considerable distance, above and below and at the mid-plane of the worm wheel, the contact is continuous. The remaining portions are in periodic engagement. The length of the worm and width of the wheel face are in no sense restricted, when the Cone design is employed. The gears may be of any desired ratio and may be cut with any desired amount of backlash, or with no backlash, in cases where none is desirable.

The "Cone" principle, in its simplest form comprises the use of a hob identical with the worm as to mating capacity, but having thread flanks thinner in cross sec-

tion than the corresponding worm flanks. (Figure 2.) When such a hob has been fed into the proper center distance, the wheel teeth have been "roughed out", but sufficient stock has been left on the tooth flanks to permit the complete refinishing of the flanks, with the hob positioned just as the worm will be in service. The necessary cutting feed is then introduced by changing the relative rotative position of the elements, introducing an angular shift in the position of the hob or blank about its axis of rotation, like taking up backlash in a gear set.

The Cone worm is produced in a manner similar to that employed in producing the gear. A cutter representing the midplane section of the gear may be utilized. (Figure 3.) The teeth of the cutter, insofar as mating capacity is concerned, are identical with the teeth of the gear. Here again, the teeth of the cutter are made thinner in cross section, to permit recutting of the thread flanks, after the designed center distance has been reached, at the end of the roughing operation.

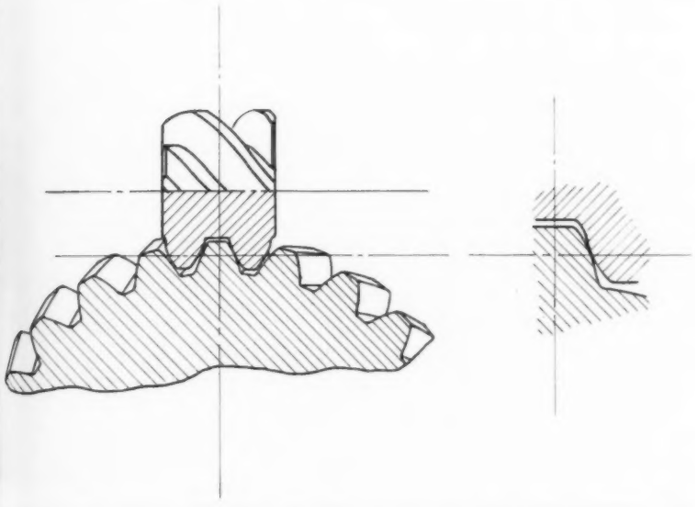


FIGURE 8—With neither element throated, the contact in worm gearing is theoretically a point.

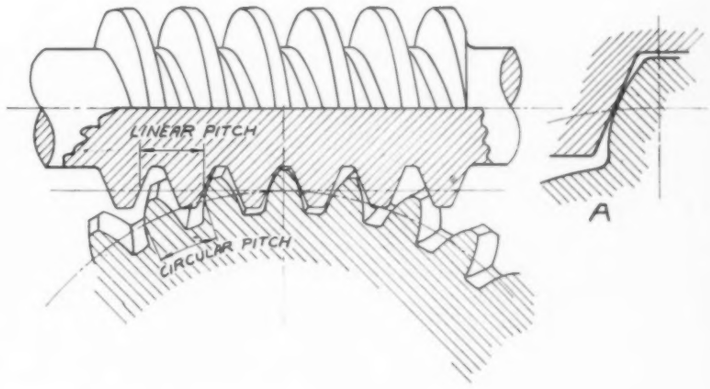


FIGURE 9—With one element throated, the contact between worm and wheel is theoretically a line.

Here also, the final form is imparted by indexing the cutter or blank about its own axis of rotation. The cutters can be repeatedly resharpened without changing the form of the worm so produced.

Large worms may be generated with fly tools, inserted blade tools, or specially generated end mills.

Top clearance for hobs and worm cutters is allowed for by providing additional root clearance in the original design.

It would seem that, having discovered a rational method of cutting the worms and worm wheels, and also a design of hob which would generate the correct form and thickness of wheel, the problem had been solved. Subsequent experience, however, proved that this was not the case. Many interesting and heartbreaking experiences were encountered, before its economical manufacture was accomplished. From a practical standpoint, some means of grinding the hob, to take care of heat treating distortion, was absolutely necessary, if accurate gears were to be produced. A further difficulty arose in connection with producing hobs having relief back of the cutting edges, so that they could be repeatedly sharpened and still maintain the original designed form.

This problem was finally solved by developing special grinding machines to impart correct form and relief to the heat-treated hob, throughout the entire length of tooth, thus permitting repeated sharpenings, without disturbing the original form.

The first equipment, used for cutting Cone gears, was an adaptation of conventional hobbing machines, by means of an attachment for effecting the finished cutting of the elements on operating centers. The next stage of development was the building of general purpose hobbing machines, peculiarly adapted for producing both worms and gears. The next stage in development was the building of two-spindle, hand-operated machines. (Figure 4.) The machines are so designed that the work piece may be fed toward one cutter, finishing one set of flanks, and then quickly shifted by hand to the other cutters, to finish the opposite set of flanks. The machine for cutting the gears is similar, except that two hobs replace the two cutters.

The first high production, fully automatic equipment was produced in connection with very small size gears. The machine followed closely the ones described above, with the exception that cams replaced the hand control, while the cutters or hobs operate in such a way that both sets of flanks are finished simultaneously. With this equipment, one operator produced 270 worms or

270 wheels per hour. More than a million sets of these gears were produced in one year's time.

The most recent advance made in connection with production equipment has been the development of larger machines, capable of cutting up to 4 in. center distance. The machines operate on substantially the same principles as the smaller equipment. A complete cycle takes less than one minute, and the spacing, lead and pressure angle can be held to within a few ten thousandths of an inch. (Figures 5 and 6.)

In addition to the above, machines were developed for checking the lead, pressure angle and spacing of the hob and worm. (Figure 7.)

CHARACTERISTICS COMPARED

Throughout this discussion, it will be seen that "throating" or "enveloping" the gear element or elements, always results in an increase in tooth contact, and thereby load-carrying capacity. Furthermore, only throated elements regenerate or reproduce themselves when wear occurs. Such elements also must be form-generated on operating centers, and must be located at assembly, within reasonable limits.

NATURE OF CONTACT

Let us now discuss the nature of tooth contact, in the various types, as an index to load-carrying capacity. When neither element is throated, as in the case of right angle spiral gears, (Figure 8), opinion is unanimous that the nature of the contact is a theoretical point. It is, of course, understood that when a load is applied, deflection takes place in the materials and consequently, the point becomes a small spot having some area of contact. This type has the least load-carrying capacity of any of the types under discussion.

Next, we consider the conventional worm gear, having one element which is throated. (Figure 9.) Early references show that gear experts were uncertain as to whether the throating of the gear element changed the theoretical contact from a point to a line. However, there seems to be general agreement now that, for all practical purposes, the contact is a line. Most of the gear experts today, in dealing with the nature of the contact produced in this type of gearing, state emphatically that the contact is a theoretical line, varying in length with different designs. It is, of course, understood that under load, this line widens out to a thin band or zone of contact. It is universally agreed that the conventional or throated worm gear carries more load for a given size than the right angle spiral gear.

We now come to the double enveloping worm gear (Figure 10). In addition to having each element envelop the other, all teeth contact full depth, being straight-sided and tangent to a common circle. As a result of this principle, we have, in addition to the line contact across the face, found in single enveloping types also a line contact extending full depth of the teeth; the double enveloping resulting in area contact.

It seems reasonable, from the above, to conclude that absence of enveloping of either member, results in point contact. Single enveloping results in line contact across the tooth face. Double enveloping results in line contact in two directions or area contact. This area contact, of course, occurs on all teeth enveloped. We, therefore, have multiple tooth area contact.

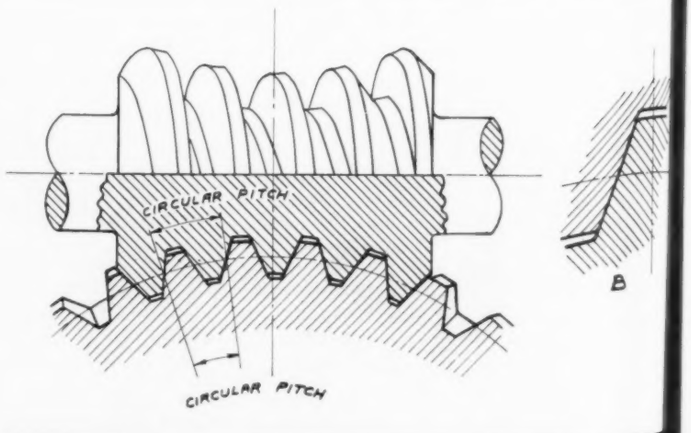
At this point, I would like to cite a specific design, to illustrate the point; we were called upon to design a unit as small and light as possible, for an aircraft application. This unit was designed, using a bronze of high strength (37,000 lb. per square in. yield point), and seven teeth in contact. To cut the weight, as much as possible, the unit was stressed to 85 per cent of the yield point. This unit has successfully passed severe tests of the Bureau of Aeronautics, and is being tooled up for high production.

NECESSITY OF ACCURATE ALIGNMENT

Where neither element is throated, as in the case of right angle helical gearing, then neither the driver nor the driven member has to be held in alignment in the direction of its axis. It is only necessary here to maintain, within reasonable limits, the center distance or distance between the axes. Going hand in hand with the extreme flexibility of this type of gearing, goes the fact that it has only point contact.

Where one element is throated or envelops the other, it now becomes necessary to hold, within reasonable limits, not only the distance between the axes, but also the position of the throated element. In days gone by, when no accurate machinery was available, the necessity for holding the throated gear element was considered to be a distinct disadvantage. For this reason, the right angle helical gear was used in many types of applications where the throated type would have given better satisfaction. Today, the necessity of aligning the throated gear element, within reasonable limits, is

FIGURE 10—With both elements throated, contact between worm and wheel assumes two-dimensional nature.



not considered to be a disadvantage, and consequently, the throated type of gear, on account of its many advantages, has largely superseded the unthroated type.

The so-called Hindley gear had to be assembled to extremely close limits in three planes, as is well known to those who have used it. It is believed that one of the reasons why the Hindley type of gear was considered to be so sensitive to alignment, had to do with the following considerations: the form imparted to the worm and worm gear elements was such that no true mating capacity existed. As neither element, as originally cut, had the correct form, it follows that a grinding of the two elements together merely tended to lap a flat spot into the elements, and it is, therefore, apparent that any attempt to assemble the elements in anything but the exact position in which they had been lapped, would produce an interference. In other words, when you got out of the hole that had been lapped between the mating surfaces, then you were into serious trouble.

FIGURE 11—Worm gearing is used in various applications on steel mill equipment.

Cone gear sets are not unduly sensitive as regards alignment. It is true, of course, that just as it was necessary, in connection with the throated conventional gear to hold the alignment of the gear element within reasonable limits, in order to utilize the additional bearing surface, so for this reason, it is necessary also to align the worm within reasonable limits, in order to further convert the line contact of conventional gearing into the area contact of the gearing. This requirement, entirely practical to secure in service, is shown by the fact that Cone gearing today is used in many types of applications and no difficulty is encountered in connection with its assembly.

Many tests have been made, during the past four or five years, in connection with the new type of worm gear, and from these tests, together with actual experience in service, standard ratings have been adopted. In this connection, for obvious reasons, an earnest effort has been made to be conservative, although the ratings may appear high at first glance.

ADVANTAGES OF DOUBLE ENVELOPE TYPE

Let us now sum up the principal advantages of the Cone design:

1. Large instantaneous contact per tooth, plus multiple tooth contact, resulting in greater load-carrying at lower unit pressures.
2. The gear, due to its construction, tends to pump the oil through the mating threads and teeth, in a manner closely analogous with the conditions found in a Kingsbury type of bearing. Thus, the oil is forced through the contacting surfaces.
3. Since perfection is always impossible of attainment in manufacture and assembly, the ultimate bearing surfaces available in any gear set, depend to some extent upon the slight wear that takes place between the elements in the early stages of operations. The Cone design permits both worm and gear to wear into the true theoretical form, whereas other types of gearing have this advantage only with regard to one of the two mating elements, the other element tending to destroy the original form when wear occurs.

APPLICATIONS

As to service history, a worm and worm wheel of this design was installed on the destroyer U. S. S. Case, about 15 years ago. When this ship was recently sold by the Government, the gear was still in perfect condition.

In 1925, the battleship U. S. S. Texas, needed replacement of the worm gears in her anchor windlass engines. One single lead worm, 14 in. in diameter, drove two gears 6 ft. 3 in. in diameter. The ratio was more than 100 to 1. The worm was of soft steel and the gear was made of bronze. These gears were subjected to severe Naval tests and are still in perfect condition, after 14 years of service. When this gear set was installed, thin sheets of lead were inserted between the worm threads and tooth flanks, and a pressure exerted to compress them. Upon removal, micrometer meas-

urements of the lead strips, disclosed that the instantaneous contact was approximately 15 square inches.

As a result of the above, the Government became quite interested in Mr. Cone's ideas regarding production of the gear, and installed many very interesting applications in the Naval service. Twelve different types of applications of Cone gears were made in some twenty-two Naval vessels at the Norfolk Navy Yard alone. The results secured demonstrated that a difficult problem had been solved. Since the birth of the new type gear at Norfolk, its usefulness has been spreading to industry as a whole.

Cone worm gears are in successful use in ratios varying from 1 to 6 step-ups, to 180 to 1 reductions; with speeds varying from 30,000 rpm. to one fifteenth of a revolution per minute; and in sizes from six feet in diameter to one inch diameter gear wheels. It has now invaded practically every field, where right angle drives are used.

DISCUSSION

PRESENTED BY

ERNEST WOOLER, Chief Engineer, Bower Roller Bearing Company, Detroit, Michigan.

G. R. SCOTT, Gear Consultant, Michigan Tool Company, Detroit, Michigan.

ERNEST WOOLER: I don't know whether I am out of order here with you fellows, as I am more interested in the automotive industry, but I heard about this paper of Mr. Scott's recently, and I thought I would come down and listen to it. I have quite a few questions I would like to ask. I have had some little personal experience with it myself, and I would like to ask:

1. What is the efficiency of the Cone type worm? Of course, I realize it is probably quite different with various ratios; for instance the 4-to-1 ratio or the 5-to-1 ratio of a passenger car rear axle may be quite efficient, whereas in a 15-to-1 ratio, as might be used on a tractor, the efficiency might be considerably less.

2. What kind of lubricant is recommended for this type of worm? I shouldn't think that an extreme pressure lubricant would be necessary, as this type worm should have so much area of contact and hence, low unit pressure.

3. How do you make a hardened worm, and is it necessary? If it has to be hardened, it would naturally distort, and I realize that it might be very difficult to grind. It may be cut in the first place from the soft metal (if I may say soft, or relatively soft metal), and have a perfectly true form of tooth, but the distortion in hardening may make the grinding of the hardened worm increasingly difficult. I know the problem has been tackled by many people, but I don't know of anyone who knows how to commercially grind a Cone type worm.

4. You mentioned a little about tolerances of assembly, but not being quite so familiar with your type worm as with other types, I would like to know what are the tolerances of a Cone type worm and wheel on, let us say, four or five inch centers, machining and assembly tolerances of center distance, longitudinally, side location, and so on.

5. You mention the Kingsbury bearing system of oiling, and I know lubrication is of major importance. I can visualize that the Cone type might be a good oiling job. Whether it is or not, I would like to know a little more about that.

6. You mention overhead worms; that is, the worm on the top, as in all of your illustrations. Is that practical? Or, wouldn't it be better to put the worm down in the bottom, right in the oil, especially for slow-speed work? Would there be enough oil getting to the worm if it was overhead?

7. Also, I would like to ask—What is the operating temperature of a passenger car rear axle, and also of a 15-to-1 reduction suitable, we will say, for a farm tractor?

G. R. SCOTT: Mr. Wooler has certainly propounded some very interesting questions, which I shall attempt to answer as concisely as possible.

1. Answering the first question, regarding the efficiency of the Cone type worm gear, Mr. Wooler is quite correct in assuming that high ratios adversely affect the efficiencies of this type of gearing, as is the case with the conventional type; but not to such a marked extent, as unit pressures are materially less in this design, on account of the greater contact area. Therefore, it follows that the coefficient of friction is materially lower, accounting for the more favorable condition.

In addition to the above, a wedge of oil is continuously being forced or pumped through the threads, instead of being scraped off.

A Cone type of gear, having a ratio of approximately 5 to 1, showed an efficiency of 99.34 per cent. At the less favorable end, an efficiency of 88.5 per cent has been secured with ratios of 50 to 1.

An approximate rule to follow in connection with the efficiency that might be expected under normal operating conditions, when using these gears, is to subtract one-fourth of the ratio from 100, and this will be the expected efficiency.

The efficiency of these gears has been established by numerous tests, carried on by the best known research laboratories in this country. All of the information regarding efficiencies quoted, is based on tests conducted by impartial sources. The efficiencies to be secured in connection with this gearing, as with other types, will of course vary with many other factors that tend to effect the efficiency of all types of gearing.

2. Coming now to the question of the type of lubricant recommended for our type of gearing, Mr. Wooler's assumption is correct that, as a result of the large area contact present, extreme pressure lubricants are not necessary nor are they recommended. We recommend the use of straight mineral oils, where the service is continuous and where the best results are desired. Very satisfactory results have been se-

cured when using the so-called 600-W, or compounded lubricants, however.

3. Coming now to the question of the necessity of hardening and grinding the worm—years of experience have indicated that it is not necessary to harden this type of worm beyond the point where it may be machined after the heat treating process. Numerous tests and years of experience have indicated that the worm, bearing as it does from end to end and for the full depth of the thread, will, in its semi-hardened condition, destroy a wheel made of the best type of bronze that has as yet been developed. Accordingly, there is no reason to grind the worm.

We have developed methods however, for grinding the worms, in unusual cases where grinding is essential. It will be understood that we have fully perfected methods and means for grinding the hobs.

It will further be understood that any slight wear on the worm will tend to remove slight inequalities in the manufacture and assembly. This, of course, is not true of the conventional worm where any change in form, produced by the worm gear on the worm element, will tend to destroy its mating capacity.

4. We now come to the question of assembly tolerances. It is not necessary for me to inform Mr. Wooler that accuracy at assembly and rigidity of mounting are highly desirable, in connection with all types of right angle gearing, where heavy loads are applied, and where smooth, quiet operation is essential. The Cone gear is no exception.

Answering directly, the question propounded by Mr. Wooler, we would expect to secure very satisfactory results with the following tolerances: center distance, plus .001, minus .002; end position of the worm, plus or minus .002; side position of the gear, plus or minus .002. Experience indicates that a shift in the Cone worm in the direction of its axis, of from .005 to .007, depending upon the particular design, is necessary in order to disturb the tooth contact .001″.

This fact, coupled with the ability of the Cone type of gear to regenerate itself when wear does occur, both with respect to the worm and the gear elements, shows that extreme accuracy of assembly, while desirable, is not essential.

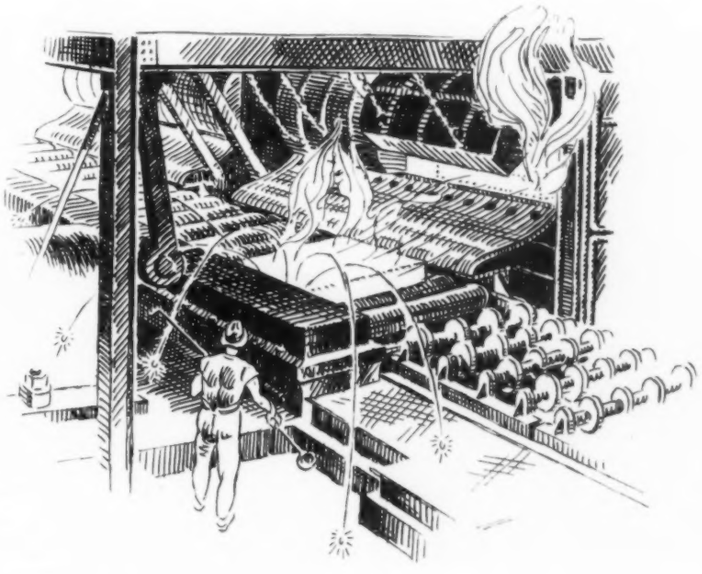
5. Mr. Wooler states that he can "visualize that the Cone type might be a good oiling job". As already pointed out, in connection with my answer concerning the efficiency of this type of gear, Mr. Wooler's assumption is well founded. This type of gearing, not as a result of any planning on our part, but in the very nature of the design, pumps the oil through the contacting surfaces instead of scraping it off.

6. Mr Wooler's question regarding the use of an over-slung worm in lieu of an underslung one, indicates that our illustrations have been misleading. As a matter of fact, where the option is left with us, we would rather recommend an underslung job than an overslung one, for the reasons set forth in Mr. Wooler's question. However, many types of applications make it necessary to utilize a design where the worm is at the top. Insofar as our experience has gone, we have not noticed any material difference in the two types.

It will be understood, of course, that suitable provision must be made to carry oil to the worm bearings, particularly where the speed of operation is slow. For high speed work, it is frequently desirable to place the worm on top, out of the oil bath, to reduce agitation. In any event, the problem would not seem to be different than that encountered with conventional gearing.

7. Coming finally to the last question, regarding operating temperatures in a passenger car rear axle, it may be said that, as the efficiency of the gear is at least equal to that of the spiral—bevel or hypoid, the temperature would not be unlike that secured with the above-mentioned gearing.

We would expect to secure, with a proper design, temperatures ranging from 150 degrees to 180 degrees. Our experiences indicated that, when using straight mineral oils, that operating temperatures as high as 200 degrees are satisfactory. A properly designed housing, however, having the necessary radiating capacity, should keep the maximum temperature within the 180 degree mark mentioned above.



DEVELOPMENT of COLD ROLLING PRACTICE

By A. J. CASTLE, Superintendent

Cold Strip and Tin Mills

INLAND STEEL COMPANY

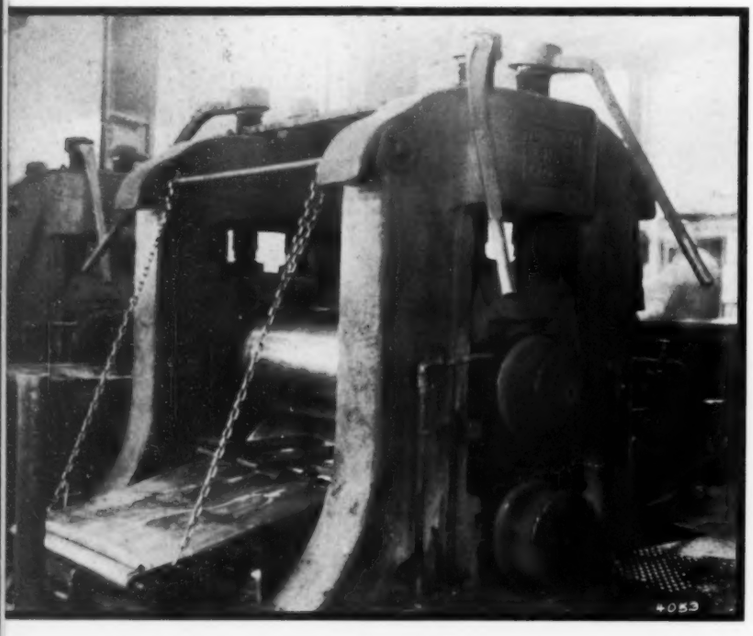
INDIANA HARBOR, INDIANA

This paper is a condensation of an address delivered October 31, 1938, before the Peoria, Illinois, chapter of the American Society for Metals, and based largely on the author's personal experience for twenty-five years in this field.

▲ THE earliest known record of any attempt at cold rolling is about the year 1495, which is verified by a sketch produced at that time by Leonardo da Vinci.

From this period, development of cold rolling was apparently quite inactive until about the year 1615, at which time there was built a hand-operated rolling mill for the rolling of lead, which was reduced to sheet form for use as gutters on houses and other applications of that nature. No further developments ensued until the year 1761, when there appeared the first published principles of flat cold-rolling. A century later, in the year 1861, the first patents were granted in Europe and England and shortly thereafter, in 1864, in the United States. By this time developments had progressed to such an extent that there came into use both water-power and horse-power to supplant the earlier human hand-power. While the earliest rolling operations were confined to soft ductile metals such as lead and gold, there was a considerable amount of cold rolling as well as hot rolling done on iron in the later periods.

View of old type cold sheet mill, as used in plants producing sheets on hand sheet mills.



It is a known fact that in the latter part of the nineteenth century there arose increased demands for flat rolled steel products, and several small mills were built in the eastern part of our country to supply this demand. From this time on, a succession of rolling mills were constructed, into each of which were built the new ideas and improvements, finally culminating in the modern high speed mills of today.

In 1907-1908 there was built at the Cuyahoga plant of the American Steel and Wire Company, at Cleveland, Ohio, a mill for cold rolling narrow strip in all grades. The department consisted of over one hundred stands and was probably the most modern cold mill of its time.

Numerous mills had been built throughout the eastern part of the United States with the idea of rolling widths up to a maximum of 10 inches. Some of these mills had been placed in tandem, but most of them were in single formation. The tandem mills, however, were not tied together, but were independent of each other, the strip being fed onto a reel after each stand. The maximum width to which material could be rolled on these mills was 14 inches. In the Cuyahoga mill all but five or six of the total of one hundred stands had rolls with faces of only 8 to 10 inches.

The material rolled on these early cold reduction mills was in great demand for household utensils, tubing for steel beds, link belts, corset stays, overall buttons, etc.

Operations in cold strip mills proceeded along these lines without any great changes until the early twenties.

At this time the automobile industry, which had developed into one of the major industries of the country, endeavored to get away from the straight lines which had predominated their design.

Up to this time, most of the steel for the manufacture of automobile parts had been made in the old hand sheet mills, which were capable of producing considerable widths of sheet well suited for forming. The

A. J. CASTLE

new demand from the automobile trade required the steel to withstand a certain amount of draw. The hot sheet mills met this demand by inserting the normalizing, or open annealing treatment into their process, which caused an added cost.

It is well known that cold rolled strip material, insofar as drawing properties were concerned, was more ductile than the product formerly made on hand sheet mills, but it was not as ductile as the sheet made by normalizing, pickling and box-annealing. It was indicated, however, that if steel could be continuously rolled in sufficient widths there were certain parts used in automobile manufacture that could well be made from cold strip material. Just how wide it was advisable or possible to cold roll continuous strip steel was the problem. After considerable thought, it was deemed possible to widen mills to approximately 20 inches, doubling the prevailing widths.

One of the greatest problems in producing cold rolled strip for automobile use was the difficulty of producing and retaining a proper surface condition because of the practice of handling material in coils. This was especially true after annealing, when the material was soft. It was quite difficult to keep the strip from breaking across the surface while uncoiling and passing through the skin mill, causing what were known as cross-breaks or whips in the material. This trouble, which was of really serious magnitude, was finally overcome by the discovery that there was a definite limit to the minimum diameter of coil which can be formed, depending on the thickness and width of the steel.

It was not long after the introduction of mills 20 inches wide that the steel producers perceived that it would be feasible to go still wider and cover an additional field of demand. By 1926, continuous cold strip mills had reached a width of 36 inches.

During this development from narrow to wider mills, it became apparent that the wider the mill, the more spring there was in the mill, or the greater deflection of the rolls due to bending. Much thought had been given to this matter with the result that the four-high design was adopted. During this period there was also developed the cluster mill, but the four-high design proved to be most efficient from all angles. The principle of the back-up roll to assist the working roll to resist flexure had been used as early as 1893 in the finishing stand of a merchant mill converted to the rolling of relatively narrow hot strip.

As the width of mills gradually increased, the old type of bearings used on the narrower mills became inadequate for the demands placed upon them by the heavy pressures required to reduce the wide strip. The early bearings employed babbitt or similar metals, which would not withstand the higher pressures and temperatures. The result was the application of roller bearings on hot and cold wide strip mills. Roller bearings had been used in other fields, but had not yet been adopted on roll necks to any great extent. More recently there has been a trend back to the babbitted type bearing of improved design, in which the bearing is flooded with oil under pressure, maintaining a continuous oil film between the bearing surfaces.

Because of the success in cold rolling wide strip material to gauges of No. 20-22 and widths up to 36 inches,

Cold rolling of sheets consisted only of a skin pass, with material handled entirely by hand.

the idea was conceived in the late twenties that it might also be possible to cold roll tin plate material, requiring widths up to 28 inches and thicknesses of .006-.012 inches. Up to this time, all tin plate had been rolled on the old style hand sheet mills. A cold mill was built at the Yorkville, Ohio, plant of the Wheeling Steel Corporation for this purpose. It was proposed to pass the material through four mill stands in tandem, use an intermediate anneal, and finally reduce to finished gauge in another pass through the four stands.

This mill was of the four-high type, of sturdy construction, and was equipped with roller bearings. It was probably the heaviest mill that had been built up to that time. Inasmuch as this company had no hot strip mill of its own at that time, it was necessary to bring hot rolled coils from other plants. These coils were usually .06 inches, which was the lightest gauge in which hot strip had then been produced in the required widths.

Due to the great pressures exerted in these mills, and the large reductions made, marked temperature rises were encountered, causing trouble in maintaining gauge. It was very difficult to prevent tearing of the strip while passing through the mills. In trying to eliminate this difficulty many different kinds of oil were tried, seeking a lubricant that would aid in the reduction process. Seeing a man wash his hands with a liquid grease-cutting "soap" and noting that it had a definite body, it was felt that this material might serve as a cold-rolling lubricant. A trial proved it to be the best material used up to that time, aiding greatly in the reduction process on this mill.

A brief period of operation with this method brought out the fact that it was not practical from a commercial standpoint to roll to an intermediate gage and anneal. With the improved lubrication, it was thought that greater reductions might be made, so that the coil might be reduced to the finished gauge—or nearly so—in one operation. This plan was tried, reducing from .06 in. to .01 in. in one pass through the four mill stands. The mill was obviously too light for the increased loads placed upon it, and vibrated heavily. It was nevertheless decided that this method of operation should be continued, as it was plainly the proper way to produce tinplate.

By this time it had been conclusively demonstrated that continuous cold rolling of wide material was practically and commercially sound, with the result that in 1928 the Wheeling Steel Corporation decided to install continuous hot and cold strip mills in their Steubenville, Ohio, plant. The hot mill was 60 inches wide, one of the widest and most modern of its time. The cold mill was 48 inches wide, designed for strip widths up to 46 inches. Both mills represent a marked increase in width over mills built up to that time.

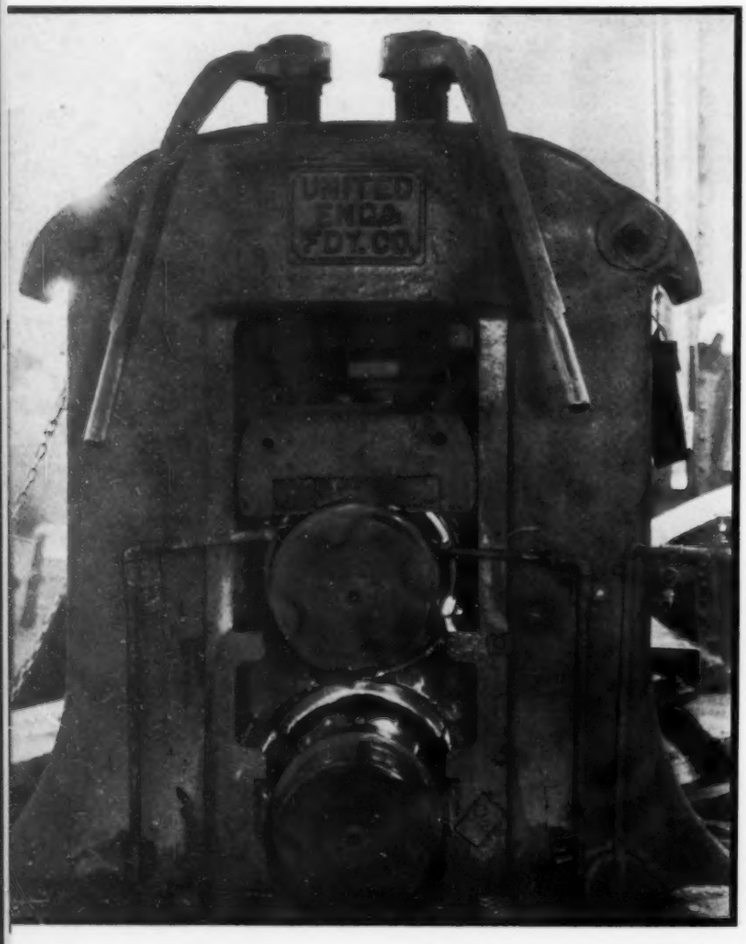
It was in this cold mill that the writer first tried palm oil as a cold rolling lubricant, which improved the process considerably. Palm oil was then tried on the tin plate mill at Yorkville plant, and resulted in greatly decreased power consumption and reduced temperature on the mill. This last item further tended to reduce the serious difficulty of spalling of rolls, due to the alternate heating and cooling of the rolls when rolling and idle. Palm oil has proved to be one of the greatest steps in the improvement of the cold reduction process.

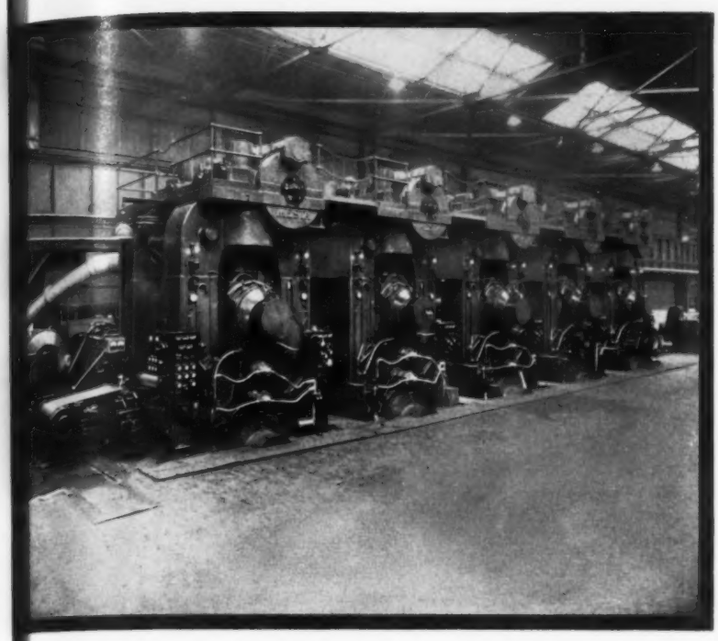
During this period, sheet customers' demands upon steel producers called for material of deeper drawing qualities, which resulted in increased research and study of the entire steel-making processes. It became apparent that the smooth surfaced sheet as then made on the cold reduction mills was objectionable due to slippage in the dies of the press, causing scratching, buckling and paneling in the drawn part.

In order to obtain the dull surface which seemed necessary for satisfactory drawing practice, Inland Steel Company carried on a considerable amount of experimental work. This company had just installed a 76 in. hot strip mill and a 54 in. cold mill which was almost immediately widened to 74 inches. The result of these experiments was the development of a method of dulling the work rolls in the skin-pass or temper mills. The dulled surface of the roll transferred a dull matte surface to the sheet as it was being skin-rolled after annealing. This type of sheet proved to be satisfactory in every degree.

This use of the dull roll also permitted cutting the material to sheet lengths before annealing, thus overcoming the difficulties encountered in cutting wide strip

Cold sheet mills consisted of little more than the housings, the rolls, and manually operated screws.





Much experimentation was necessary before the present cold reduction process was brought into successful use.

to length in the soft state. It was thought that the dull-surfaced skin roll would allow for proper skin-rolling of wide sheet material in short length without the formerly required tension, and would give a flat commercial sheet due to uniform elongation.

In the search for improved drawing qualities, it was realized that higher annealing temperatures were required. With the smooth surfaced sheet as produced in the cold reduction process, higher annealing temperatures tended to cause annealing stickers. In the effort to overcome this difficulty, it was found that dulling the rolls in the last stand of the tandem mill would transfer dullness on to the strip, which would prevent stickers even when annealing at temperatures 100 degrees F. higher than previously. Thus, a material improvement in drawing qualities was effected, and due to this improvement, other plants soon installed wider strip mills.

In 1933, Inland decided to install cold reduction mills for the manufacture of tin plate. Inasmuch as they had not previously made any tin plate, they were confronted with the problem of producing material suitable for all grades of tin plate. No old style hand mills were available to turn out the orders which were difficult to produce on the continuous mill.

One difficulty encountered with tin plate from the continuous mills was fluting or paneling of the material on certain jobs where there was no draw but simply a forming action. Its occurrence was due to lack of sufficient reduction on the temper mills after annealing. The difficulty could be overcome by using some kind of lubricant in the temper rolling, but this would require another cleaning process before tinning, with added cost.

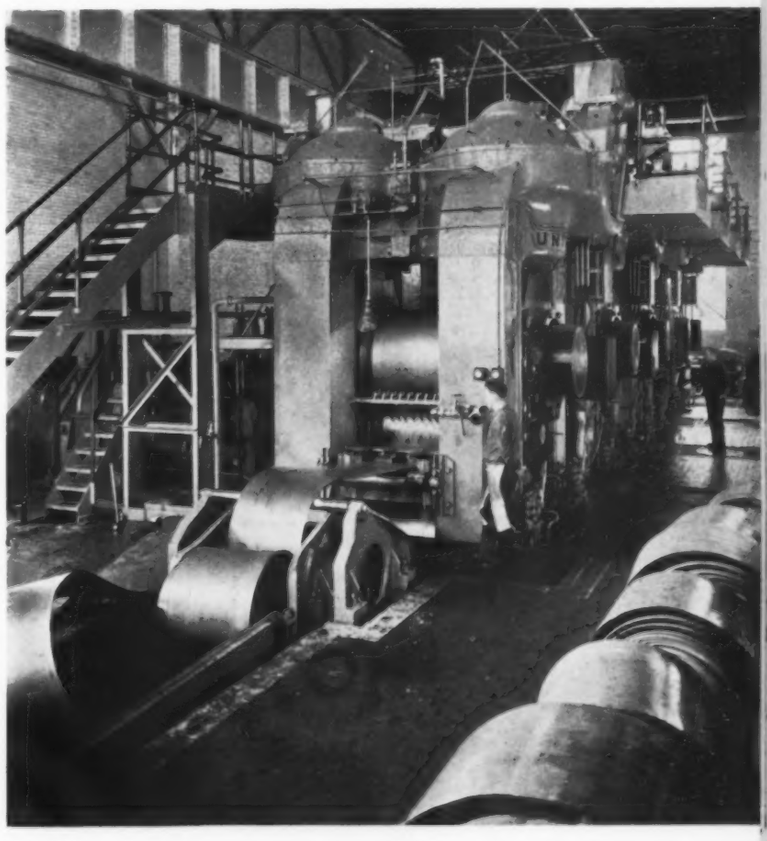
After the installation of cold reduction mills at Inland, many experiments were conducted in the effort to develop a solution to this problem, and it was finally found that by using a skin pass through dulled rolls, followed by a pass through smooth rolls, sufficient reduction could be given to produce a sheet free from fluting or paneling, yet with satisfactory flatness and surface characteristics.

The use of dulled rolls in the various applications mentioned was an innovation in the cold rolling processes, and patents were issued on the ideas. The practice, however, is now well known and is in general use in the industry.

With these various improvements in cold rolling methods, it became possible to use higher rolling speeds. The new mills were therefore built larger and heavier, with higher power on the mill drives. Whereas the first mill erected at Wheeling Steel Corporation had a maximum speed of 350 ft. per min., the modern cold mill operates up to 1500 ft. per min. Production per mill unit has likewise increased almost fifty-fold.

The history of this development is a remarkable record of progress, and a greatly reduced product cost has resulted. It is interesting to note, however, that although millions of dollars have been spent by the steel industry for the installation of these modern mills, the steel companies have not themselves derived much benefit from the lower cost, but have passed on the greater part of this saving to the users of flat-rolled steel, to the ultimate benefit of the public at large.

Modern equipment for cold rolling is heavily constructed, with great accuracy and high speed essental characteristics.



ACCELERATION of TANDEM Cold STRIP MILLS

By T. R. RHEA and M. J. LEDING

Industrial Department

GENERAL ELECTRIC COMPANY

SCHENECTADY, N. Y.

▲ OPERATING men have been aware of the fact that with screwdown settings on their tandem cold strip mill unchanged, the metal does not come down to gauge until the mill is nearly up to speed. Thus, for example, an 1800 fpm. 42 in. tin plate mill requiring 10 sec. to accelerate from a threading speed of 100 fpm. will roll approximately 142 ft. of strip during the accelerating period. Much of this strip may be off gauge, so the operators have rightly demanded shorter and shorter accelerating times.

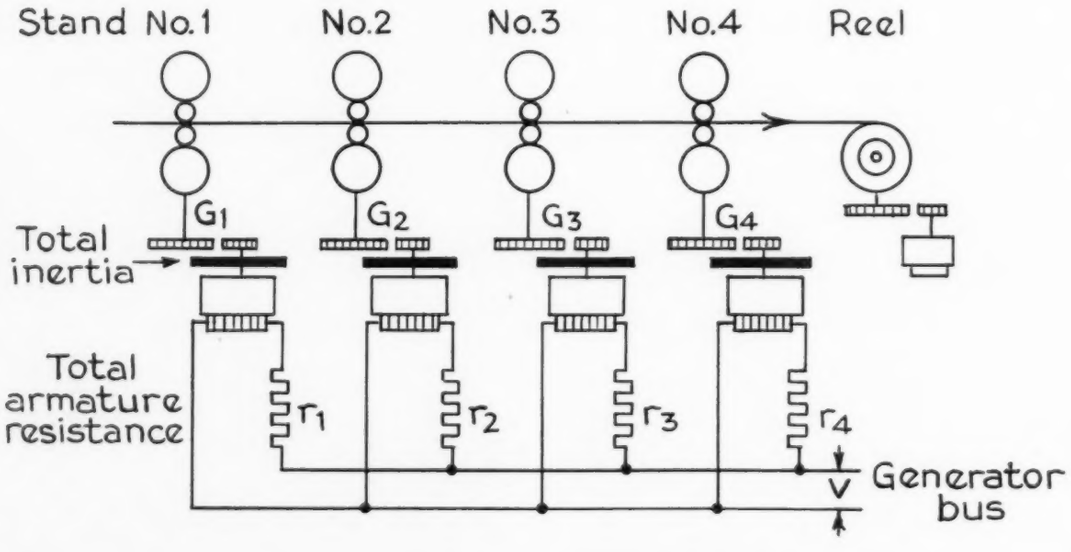
However, with the advent of shorter accelerating times, when waste should have decreased, it didn't always decrease. A new bug-bear had arisen to torment operating men—they were troubled with strip breakage and strip wrinkling which brought in spoilage and, too often, roll changes.

At this point engineers began to wonder how strip tension varied as a tandem mill accelerated and decelerated. Could the tension variations be predicted? Many theories were advanced as to how to eliminate the tension variations, with the inertia of the mill and drives receiving most of the blame.

It is the purpose of this paper to start some mathematical thinking on the problem of tension variations between stands during the acceleration and deceleration of a modern high speed tandem cold strip mill.

The authors realize that the salable product of a cold strip mill is strip of proper gauge and not tension be-

FIGURE 1—Diagram of tandem cold strip mill, in which motors must accelerate as a unit, regardless of respective individual characteristics.



M. J. Leding and T. R. Rhea, co-authors, shown at the meeting, September 29, 1938, held in conjunction with the National Convention in Cleveland, Ohio.

tween stands. But we all know that tension between stands affects gauge, also we feel that strip speed affects gauge. Still no data, so far as the authors know, have been collected on these important facts.

This paper presents a method of calculating strip tension changes and offers methods of minimizing these changes.

The authors propose the following attack on the problem and then in the light of their investigation will comment on existing theories of controlling tension variation.

THEORETICAL CONSIDERATIONS

A tandem cold strip mill, as shown by Figure 1, consists of a number of direct current motors which are considered effectively geared together by means of the strip and must perforce accelerate as a unit as voltage is applied, regardless of what may be the respective field settings, inertias, or armature circuit resistances. It is, of course, assumed that the strip is under tension at all times for the theory breaks down in case of a loop between stands, the inevitable result of excessive loss of tension.

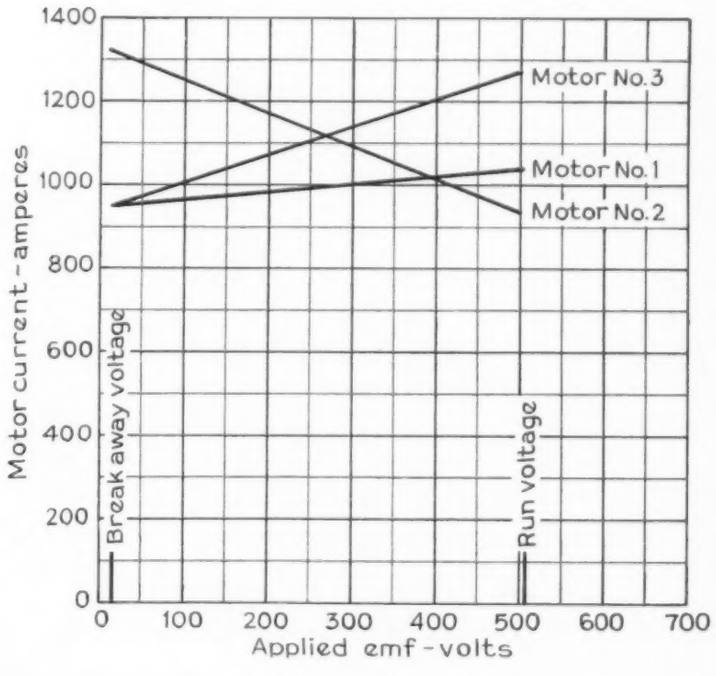
The complete mathematical solution for the acceleration of such a mill as it affects tension between stands is given in the appendix. This mathematical solution makes several additional assumptions, viz: (1) the voltage applied to the group, varies uniformly with time, when accelerating or decelerating. (2) Each motor has constant excitation, that is, the useful flux in the motor is constant. This excitation is such that the desired tension is obtained at full steady state running speed. "Steady state" running speed means the running speed remains constant, or all speed transients have disappeared. This excitation remains constant during acceleration and deceleration, so, of course, there is no compounding. (3) The rolling torque for each stand remains constant.

The physics underlying the mathematics are simple and easily understood. Until the mill breaks away from rest, the current and, therefore, the torque in each motor is limited by its armature resistance only. The current to each motor at any speed and applied voltage will be determined by its armature resistance and its back emf. Neglecting inertia effects, the current, as will be shown in the appendix, will vary in a straight line with voltage from the breakaway value to the final running value, as shown in Figure 2. Since these differences in current change the torques produced by the various motors, and the rolling load is assumed constant, these torque changes can only appear as changes in tension between stands.

Here we find, even though the WR^2 values are entirely neglected, that, except for certain selected values of armature circuit resistance, tension changes may appear during the accelerating and decelerating periods.

Superposed on the above effect is the effect of the inertias. Assuming that the applied voltage is being raised uniformly at a definite rate, one motor with a very low resistance may be getting more current than it needs for accelerating its own WR^2 and is, therefore, passing it on through the strip, in the form of increased tension, to another motor which may have a relatively higher armature circuit resistance. The motor with such relatively high armature circuit resistance would have a deficiency of accelerating current and torque

FIGURE 2—Neglecting inertia effects, current varies in a straight line with voltage from the breakaway value to the final running value.



for its own inertia and would need help. This effect is shown graphically in Figure 3.

From this discussion it may be seen that armature circuit resistance plays a very important part in tension variations between stands. In fact, in some actual cases the tension variations from thread to run due to improper resistance values were greater than the variations due to inertia. In other words, if a mill had no inertia whatever there still might be tension variations from thread to run. In such case the tension variations would, however, be independent of accelerating time and would depend only on applied voltage.

THEORETICAL PERFECT BALANCE

From the mathematical solution, it is theoretically possible to balance the resistance and inertia of a mill, so that there will be no tension variations between stands from thread to run during acceleration irrespective of the accelerating time.

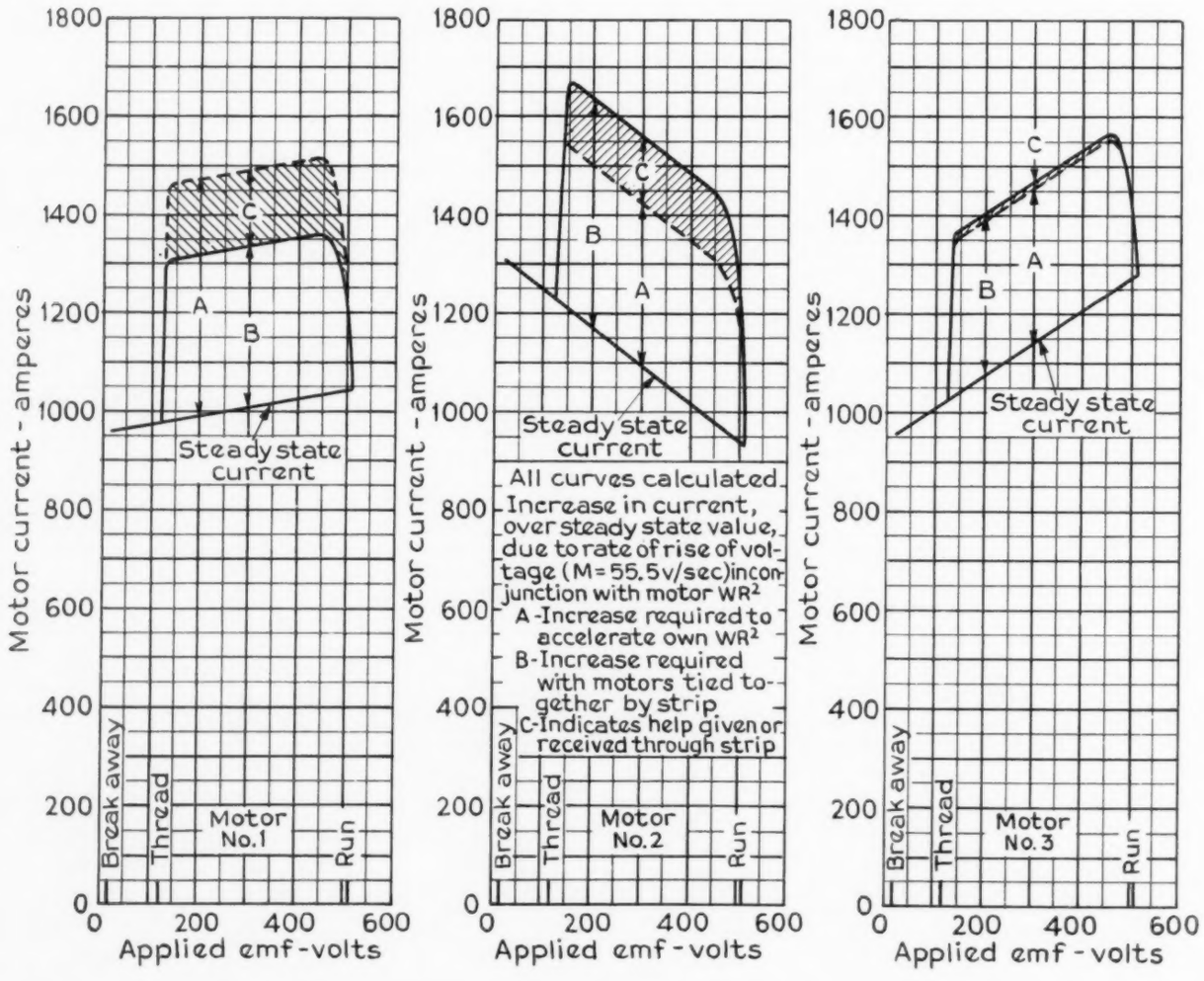
This theoretically perfect balance is possible for one rolling schedule only with one definite set of speed relationships (i.e. drafts) and loads on the motors. The theoretically perfect balance is immediately destroyed if the load relationships and the speed relationships are upset.

The conditions for perfect balance for a particular rolling schedule are:

(a) The total resistance drop in volts for the actual running load current must be the same for each motor; that is, the total armature resistance of each motor circuit must be adjusted so that the IR drop due to the running load is the same for each motor. If this condition is met, the current, as shown by Figure 4, taken by each motor is independent of the applied voltage from thread to run. It should be noted that Figure 4 is the same as Figure 2 except that the resistances have been adjusted.

(b) Once the resistances have been adjusted to meet the above conditions, the WR^2 of each motor must be selected (in its manufacture) so that

FIGURE 3—Graphical representation of current and voltage values, considering inertia effects of motors.



the IR drop due to accelerating current will be the same for each motor for the particular schedule.

For perfect balance, the conditions must be met in the above order.

Obviously, from the above discussion, the balancing of inertia alone, that is, making the inertia proportional to the motor horsepower, does not mean freedom from variation of tension during acceleration. Neither does the making of the ratio of stored energy to the horsepower rating the same for all motors accomplish the desired result. The desired results must be accomplished by a combination of inertia and resistance factors based on a particular rolling schedule. If the speed relationships are thereafter changed due to a change in rolling schedule, the accelerating currents and their IR drops will change and destroy the perfect balance. When this happens, a change in tension between stands results during acceleration and deceleration.

The authors wish to hastily deny, at this point, that they are proposing adjustable inertia flywheels or adjustable line resistances. This will be discussed in the conclusion.

TESTS MADE

A great number of tests and observations have been made on several tandem cold strip mills to check the formulae advanced in this paper. Figure 5 shows data taken on a three-stand tandem sheet mill equipped with tension indicating devices between stands. This figure also shows the comparison of tests and calculated data. The check between test and calculated results is fairly good for currents and somewhat more erratic for tension between stands during acceleration. Figure 6 shows the test and calculated results on a four-stand tandem tin plate mill, while Figure 7 shows calculated results on a different four-stand tandem tin plate mill.

From a great number of tests, there was a sufficiently close check between calculated results and tests to indicate the theory advanced to be correct, but there were sufficient discrepancies to cause some of the assumptions upon which it is based to be questioned.

Apparently the basic assumption, that the rolling torque required remains the same regardless of speed, is to be questioned. With no change in screwdown settings whatever it was found, assuming constant flux, that the total torque needed by the mill was from 10 to 15 per cent less at threading speed than at running speed. This is seen in Figure 5 and Figure 6, which show less current at threading by test than by calculation and, therefore, for the mill as a whole, less torque. This observation fits in with the observation that with screwdown settings unchanged, the metal does not come down to gauge until the mill is nearly up to speed. The authors hesitate to advance any theory to explain

FIGURE 4—With the same IR drop due to running load, current taken by each motor is independent of applied voltage.

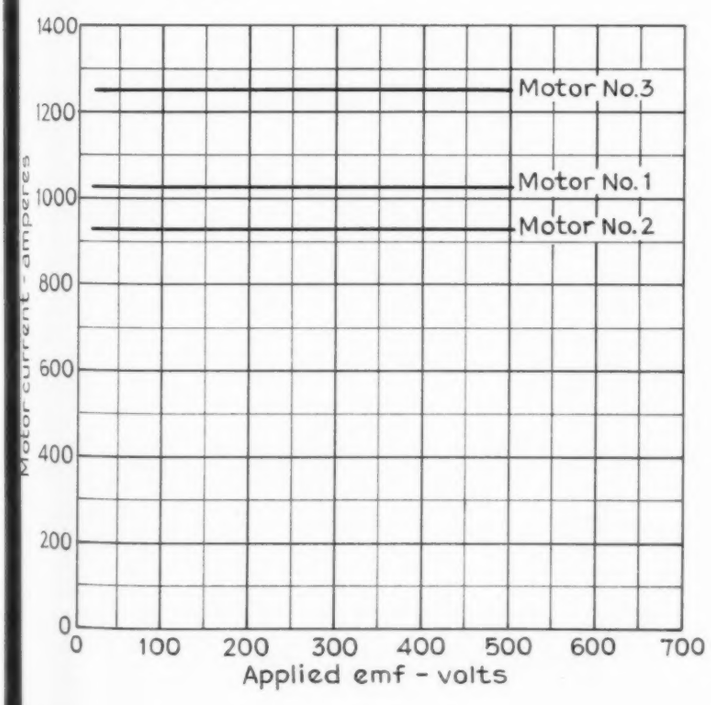
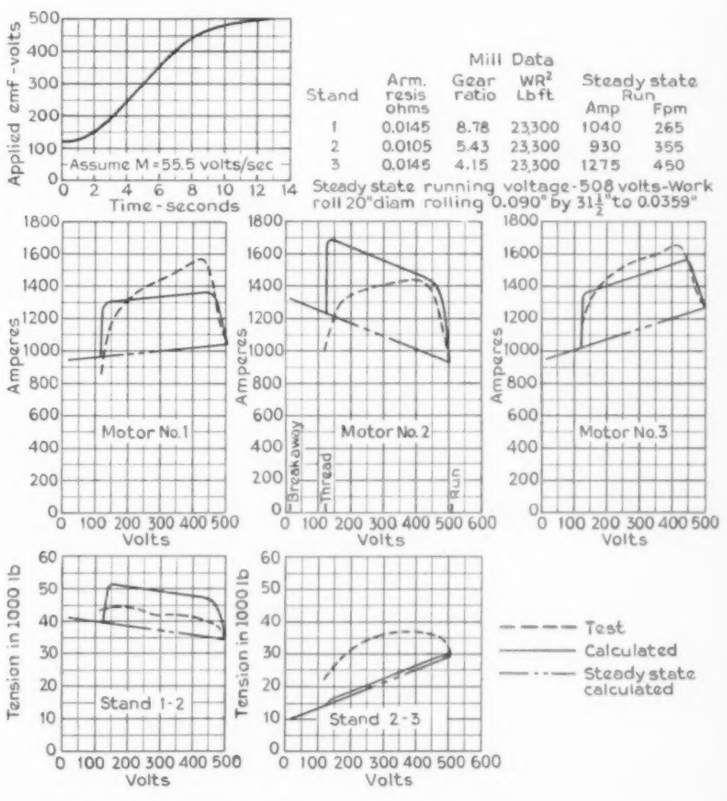


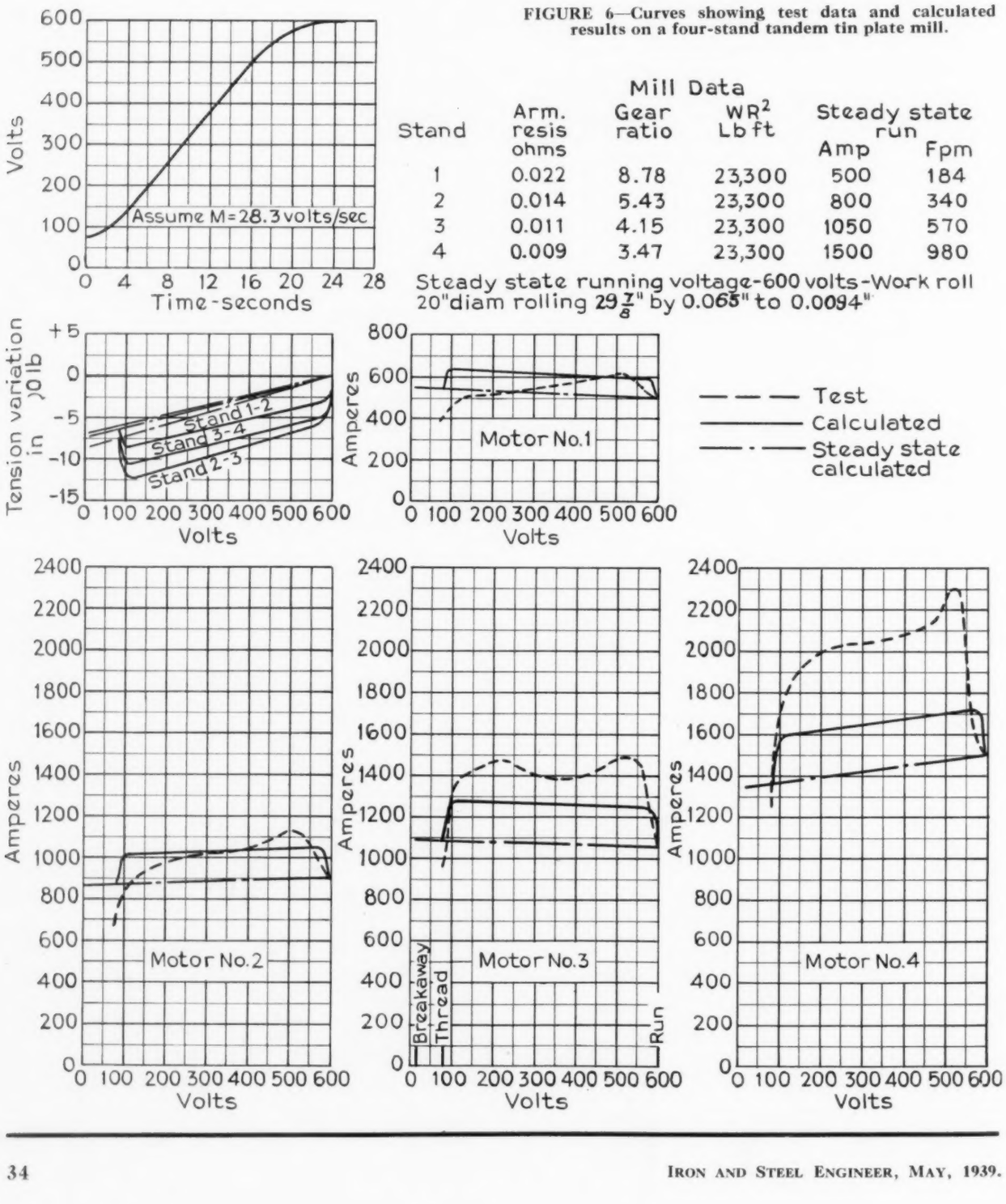
FIGURE 5—Curves showing data taken on a three-stand tandem sheet mill. Test data and calculated figures are compared.


Applied emf - volts
Assume M=55.5 volts/sec
Time - seconds
Mill Data
Stand | Arm. resis ohms | Gear ratio | WR² Lb-ft | Steady state Run Amp | Fpm
1 | 0.0145 | 8.78 | 23300 | 1040 | 265
2 | 0.0105 | 5.43 | 23300 | 930 | 355
3 | 0.0145 | 4.15 | 23300 | 1275 | 450
Steady state running voltage-508 volts-Work roll 20"diam rolling 0.090" by 31½" to 0.0359"
Amperes
Motor No.1
Motor No.2
Motor No.3
Breakaway
Thread
Run
Volts
Tension in 1000 lb
Stand 1-2
Stand 2-3
Test
Calculated
Steady state calculated

these observed facts. Perhaps it is due to the work rolls or back-up rolls deforming differently at low speeds than at high speeds. It does not seem to be due to loss of tension between stands during threading, since it is observed to a lesser degree even with an increase in tension during that period.

It is hoped that tests will be made to show the effect of speed on gauge quantitatively. Say, with the screw-down and rheostat settings unchanged, a given strip were rolled at several different speeds, after each speed change, the thickness of the strip between stands being "miked" or calculated from the speed relationships. These results, properly plotted, would point out the nature of this phenomenon that is believed to exist. Then more work and investigation would need to be done to see if tension variation can bring the metal on

FIGURE 6—Curves showing test data and calculated results on a four-stand tandem tin plate mill.


Volts
Time-seconds
Assume M=28.3 volts/sec
Mill Data
Stand | Arm. resis ohms | Gear ratio | WR² Lb ft | Steady state run Amp | Fpm
1 | 0.022 | 8.78 | 23,300 | 500 | 184
2 | 0.014 | 5.43 | 23,300 | 800 | 340
3 | 0.011 | 4.15 | 23,300 | 1050 | 570
4 | 0.009 | 3.47 | 23,300 | 1500 | 980
Steady state running voltage-600 volts-Work roll 20"diam rolling 29 7/8" by 0.065" to 0.0094"
Tension variation in lb
Stand 1-2
Stand 3-4
Stand 2-3
Volts
Amperes
Motor No.1
Test
Calculated
Steady state calculated
Motor No.2
Motor No.3
Motor No.4
Breakaway
Thread
Run

gauge sooner and, thus, reduce the amount of off-gauge material during the accelerating period.

On several tandem mills, the control has been arranged to give an increase in tension at threading speed. This is accomplished by strengthening the fields of motors 1 and 2, allowing them to drag somewhat. This field strengthening effect is reduced as the mill comes up to speed, until normal running speed and tensions are reached. There is good evidence that this scheme brings the strip on gauge somewhat quicker and, thus lessens the amount of off-gauge material obtained during acceleration. The operators have available tension indicating devices which permit them to avoid tension values which would cause strip breakage.

It would seem therefore, that in view of this discrepancy in the basic assumption of the mathematical theory set forth that the formulae developed for balance are of value qualitatively, but are not to be trusted too far quantitatively.

PRESENT PRACTICE

There are many forms of cold strip mill control which various operating men use successfully in rolling cold strip. These methods were mainly devised to hold preset tensions between stands under steady state running conditions, i.e. with the rolling speed remaining constant. Among the control methods now in use for this purpose are:

(a) Current regulators on the individual motors.
(b) Various forms of compounding the main drive motors.
(c) Tension measuring devices between stands which automatically control tension or merely indicate it.
(d) Standard shunt wound motors with normal speed regulation and control with vernier rheostats.

A good crew can roll steel successfully with any of these methods.

As regards the various methods of control, no comparative data are available on the variations in tension or, more important, on the amount of off-gauge material they may eliminate or introduce during the accelerating period. The authors will comment briefly on some of these methods.

CURRENT REGULATIONS

Current regulators inherently attempt to hold constant current, even during the accelerating period. To make a tandem mill accelerate properly, it is necessary to adjust the current settings upward to provide the necessary increase in current to accelerate the motor WR^2. This is usually an experimental adjustment for a particular schedule. When other schedules are set up, these so-called "forcing adjustments" need to be changed, but in practice seldom are readjusted.

It is the authors' belief that the use of current regulators is not justified, since straight shunt or even slightly compounded motors will attempt to adjust themselves, at least to some degree, to take the necessary accelerating current.

The authors appreciate they are treading on controversial ground, since there are a number of tandem cold strip mills now in successful operation employing these current regulators and the operators swear by them. On the other hand, there are even more tandem cold strip mills in successful operation that do not employ them. Perhaps this paper will stimulate other papers which will cause the authors to "eat their words".

COMPOUNDING

It was found mathematically, and also by common sense, that the compounding of each motor to give it a drooping speed-load characteristic is of some practical value in assisting to maintain tension during acceleration. Compounding is discussed mathematically in Part II of the appendix. Since it is theoretically possible to balance a mill to maintain tension between stands for only one particular rolling schedule, the variations of tension due to a change in rolling schedule are neutralized to some extent by the addition of compounding. Such compounding is easily adjusted in practice, while it is practically impossible to adjust armature circuit resistance and inertia to fit each rolling schedule change.

The effect of compounding in a tandem cold strip mill is very difficult to deal with mathematically during acceleration as far as the inertia effects are concerned, but approximation can be made showing the trend. Figure 8 shows the theoretical effect of adding 5 per cent and 50 per cent cumulative compounding to each motor with the steady state run conditions as given in Figure 5. It is seen that compounding attempts to hold the tension at a value more nearly equal to the running value and compensates somewhat for the improper resistance values. However the addition of such an impractically large amount of compounding as 50 per cent is not a cure-all, as shown by Figure 8.

It is difficult to see much value in compounding for steady state running conditions. Once steady state running conditions are reached, the current held by each motor is practically constant and there compounding can have little effect. From the many tests taken variation in tension was seen to occur only when the operator made a screwdown adjustment, after which the vernier rheostat was used to bring the tension between stands to the desired value.

The theory that there are hard and soft spots in the steel which cause sudden changes in tension between stands is held by some engineers. The authors can find no evidence on test charts of the effect of such spots either on current input to motors or on tension measured between stands. If such spots exist, their duration is so transitory that the electrical equipment can do nothing to compensate for them.

Even the effect of a weld in welded strip, passing

Mill Data:- Stand	Arm. resis ohms	Gear ratio	WR^2 lb ft	Steady state run Amp	Fpm	Volts
1	0.02590	14.10	1995	380	280	600
2	0.01860	5.26	7500	1270	533	600
3	0.01765	3.69	7500	1630	803	600
4	0.01250	2.10	23000	1450	1200	600

M = 93.7 v/sec - Work roll 18"diam - rolling $28\frac{3}{4}$"x 0.072"to 0.012"

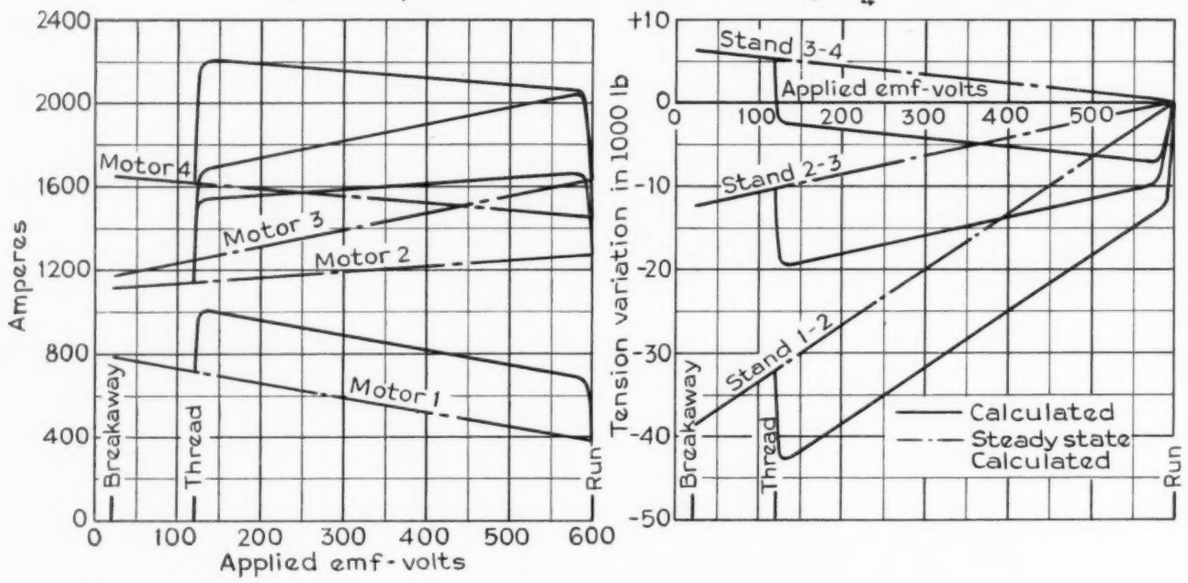
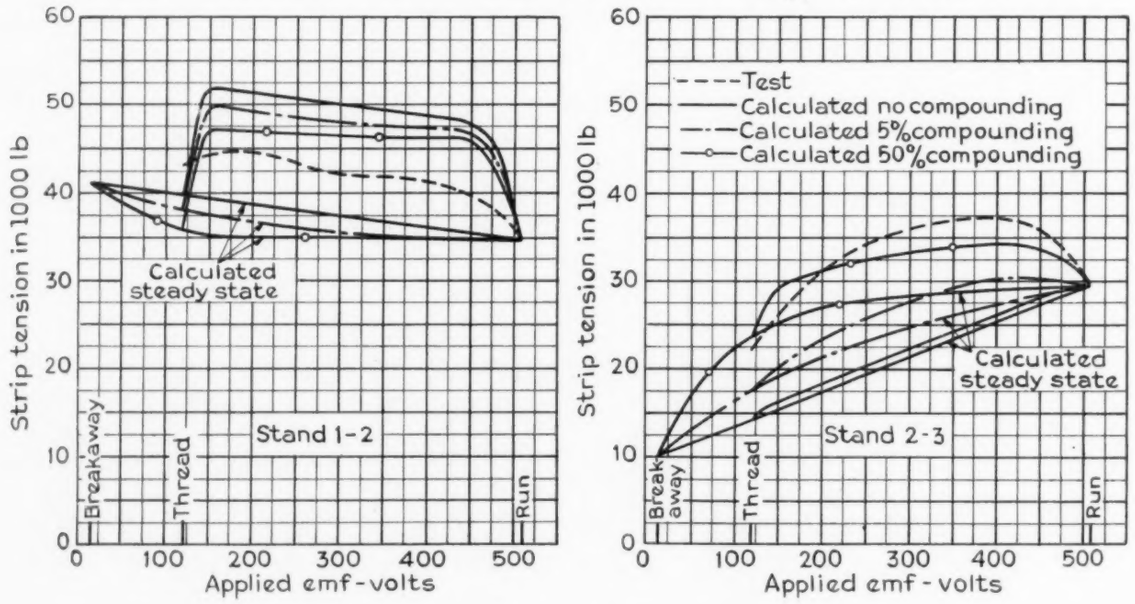


FIGURE 7—Curves showing calculated results of current and tension values for a four-stand tandem mill.

FIGURE 8—Curves showing theoretical effect of adding 5 per cent and 50 per cent cumulative compounding to each motor.

Calculated effect of cumulative compounding on tension with applied voltage, steady state run mill data as given in Fig. 5, assumed $\frac{ds_3}{dt}$ = 40 rpm/sec



through the mill is ironed out so quickly by the inertia of the rotating parts that its effects are not apparent on graphic charts.

CONCLUSION

The authors can best sum up the results of this study by making rather general recommendations for the selection of motors and control for a tandem cold strip mill:

(1) Select the motor rating for each stand to meet the expected rolling load, not permitting the desire for duplication of motors to be carried too far. Such an arrangement is inherently in better balance than where a 1500 hp. motor is called upon to carry a 500 hp. load.

(2) Adjust, at least roughly, the total armature circuit resistance for each motor so that for the most popular schedule of the mill, the IR drop is about the same for each motor.

(3) Select motors with as low WR^2 as possible, consistent with economy. Since the tandem mill is called upon to roll more than one schedule, and since balance can be obtained only for one particular schedule, better over-all operation will be obtained if the effects of WR^2 are minimized.

(4) Provide some form of tension indicating device between stands. The limit of tension which a particular strip will stand without breakage can be avoided, only if the operators know what values of tension are being obtained. A tension indicating device will also warn the operators when the lower limit of tension is approached.

(5) Some form of compounding, easily adjusted, appears to have some value in holding more nearly constant tension during acceleration. Such an arrangement is now in successful operation on several tandem mills.

Thus, it is seen that as regards a given group of schedules for a given mill, we must juggle intelligently the motor rating, armature circuit resistance, inertia, gear ratio and compounding for each motor, if it is desired to minimize tension variations between stands.

APPENDIX

MATHEMATICAL THEORY

Assumptions

(1) The main drive motors are rigidly tied together by the strip, which is under tension, and maintain their speed relationships at all times.

(2) The voltage applied to the group varies uniformly with time during the acceleration or deceleration period.

(3) The excitation of each motor is such that the desired tension is held at full steady state running speed.

For Part I of the appendix, it is assumed that the excitation remains constant during acceleration and deceleration, so there is no compounding.

For Part II of the appendix, compounding is included.

(4) The rolling torque at each stand required to reduce the strip is constant; this torque includes the mill losses. Rotor losses in the motors are neglected.

(5) The control for the reel motor is laid out to hold constant tension between the last stand and the reel.

Procedure

In attacking the problem of acceleration of a tandem cold strip mill, the procedure is as follows:

(a) The torque produced by each motor is assumed transferred through the gear ratios to the finishing stand motor shaft. In this way the total torque produced may be added directly.

(b) All inertias are transferred to the same reference shaft.

(c) The rolling torques are referred to this reference shaft.

(d) The total torque produced by all motors is equated to the torque required to accelerate the composite inertia plus the torque required for rolling. From this fundamental equation the speed of the system is found as a function of time.

(e) Each individual motor torque equation is then found as a function of time. This torque minus the torque required to accelerate its own inertia and minus the constant rolling torque gives the surplus or deficit of torque produced by that motor at any instant of time during acceleration.

(f) This surplus or deficit of torque can only appear as a surplus or deficit of strip tension from the final steady state running value and is transferred through the strip as increased or decreased tension to assist or receive assistance from the rest of the system during acceleration. Of course, the entire concept is invalid if the mill throws a loop.

The time reference point is at a value of applied voltage, V_0, at which the system just breaks away from rest. The formulae which apply between the limits of breakaway and full voltage are readily applicable to threading values of voltage which are above breakaway.

The theory is easily applicable to mill deceleration.

A three-stand mill is considered for simplicity. The formulae can be extended by inspection to any number of stands. The finishing stand is always the point of reference.

Nomenclature

V	—	Voltage applied to common bus at any instant, volts.
e	—	Counter-emf., volts.
i	—	Instantaneous motor line current, amp.
r	—	Armature circuit resistance, resistance from common bus through the motor armature, ohms.
Φ	—	Useful flux per pole, lines.
p	—	Number of poles per motor.
N	—	Number of armature conductors per motor.
s	—	Instantaneous speed of motor, rpm.
a	—	Number of parallel paths through armature.

$$Z = \frac{p\,N}{a \times 60 \times 10^8}$$

k —$Z\phi$
T_M —Instantaneous air gap torque of motor, lb.ft.
T_L —Rolling torque which includes the torque due to final steady state running strip tension before and after the stand, lb. ft.
σ —Final steady state running speed, rpm.
T_{acc} —Accelerating torque, lb. ft.
WR^2 —Inertia of rotating parts of mill stand and motor armature referred to motor shaft, lb. ft.^{2}
t —Time, seconds.
A, B
C and D—Constants defined in text by equations (7) and (8).
V_0 —Breakaway voltage, volts.
M —Rate of rise of voltage, volts/sec.
ϵ —Base of natural logarithms.
T_p —Surplus or deficit of torque at a motor available for changing strip tension from final steady state running value, lb. ft.
P —Tension variation between stands from final steady state running value, lb.
FPM—Strip speed between stands, feet per minute.
D —Diameter of working roll of stand, inches.
G —Gear ratio.
ϕ_0 —Constant flux due to main shunt field in case of compounding, lines.
K —Proportionality factor between flux due to series excitation and motor line current, lines/amp.

Mathematical Steps

In the study of the performance of a d-c. motor there are three important equations:

The voltage equation (neglecting inductance):

$$V=e+ir. \tag{1}$$

The counter-emf equation:

$$e=\frac{\Phi\, p\, N\, s}{a\, 60\times 10^8}=Z\,\Phi\, s=k\, s. \tag{2}$$

The torque equation:

$$T_M=7.05\, Z\,\Phi\, i. \tag{3}$$

Part I

Since the mill is considered geared together by the strip, the ratio of instantaneous running speeds is the same as the ratio of final steady state running speeds, thus, the following equation in the light of sections (a) to (d) of the procedure may be written at once:

$$T_{M1}\frac{\sigma_1}{\sigma_3}+T_{M2}\frac{\sigma_2}{\sigma_3}+T_{M3}=T_{acc1}\frac{\sigma_1}{\sigma_3}+T_{acc2}\frac{\sigma_2}{\sigma_3}+T_{acc3}+T_{L1}\frac{\sigma_1}{\sigma_3}+T_{L2}\frac{\sigma_2}{\sigma_3}+T_{L3}. \tag{4}$$

From the fundamental motor equations (1) to (3) it is found that

$$T_M=7.05\, k\left[\frac{V-ks}{r}\right]. \tag{5}$$

Also, by definition;

$$T_{acc}=\frac{WR^2}{308}\frac{ds}{dt}. \tag{6}$$

Substituting equations (5) and (6) in equation (4) and re-arranging,

$$\frac{1}{308}\left[WR_1^2\left(\frac{\sigma_1}{\sigma_3}\right)^2+WR_2^2\left(\frac{\sigma_2}{\sigma_3}\right)^2+WR_3^2\right]\frac{ds_3}{dt}+7.05\left[\frac{k_1^2}{r_1}\left(\frac{\sigma_1}{\sigma_3}\right)^2+\frac{k_2^2}{r_2}\left(\frac{\sigma_2}{\sigma_3}\right)^2+\frac{k_3^2}{r_3}\right]s_3=7.05\left[\frac{k_1}{r_1}\frac{\sigma_1}{\sigma_3}+\frac{k_2}{r_2}\frac{\sigma_2}{\sigma_3}+\frac{k_3}{r_3}\right]V-\left[T_{L1}\frac{\sigma_1}{\sigma_3}+T_{L2}\frac{\sigma_2}{\sigma_3}+T_{L3}\right], \tag{7}$$

or

$$A\frac{ds_3}{dt}+Bs_3=CV-D. \tag{8}$$

Assuming that

$$V=V_0+Mt, \tag{9}$$

since the system has inertia, s_3 cannot change immediately, so that when

$$t=0,\ s_3=\frac{CV_0-D}{B}=0, \tag{10}$$

the complete solution of equation (8) is

$$s_3=\frac{ACM}{B^2}\left[\epsilon^{-\frac{B}{A}t}-1\right]+\frac{CM}{B}t. \tag{11}$$

As outlined in section (e) of the method of procedure, the surplus or deficit of torque at each motor is next determined.

$$T_p=T_M-T_{acc}-T_L. \tag{12}$$

Substituting equation (11) in equations (5) and (6) and the resultant equations in equation (12), the following equations result for the total variation of motor torque from the final steady state running values:

$$T_{p3}=7.05\frac{k_3}{r_3}\left[V_0+Mt\left(1-k_3\frac{C}{B}\right)\right]-T_{L3}+\frac{CM}{B}\left[1-\epsilon^{-\frac{B}{A}t}\right]\left[7.05\frac{k_3^2}{r_3}\frac{A}{B}-\frac{WR_3^2}{308}\right]. \tag{13}$$

$$T_{p2}=7.05\frac{k_2}{r_2}\left[V_0+Mt\left(1-k_2\frac{\sigma_2}{\sigma_3}\frac{C}{B}\right)\right]-T_{L2}+\frac{CM}{B}\frac{\sigma_2}{\sigma_3}\left[1-\epsilon^{-\frac{B}{A}t}\right]\left[7.05\frac{k_2^2}{r_2}\frac{A}{B}-\frac{WR_2^2}{308}\right]. \tag{14}$$

$$T_{p1}=7.05\frac{k_1}{r_1}\left[V_0+Mt\left(1-k_1\frac{\sigma_1}{\sigma_3}\frac{C}{B}\right)\right]-T_{L1}+\frac{CM}{B}\frac{\sigma_1}{\sigma_3}\left[1-\epsilon^{-\frac{B}{A}t}\right]\left[7.05\frac{k_1^2}{r_1}\frac{A}{B}-\frac{WR_1^2}{308}\right]. \tag{15}$$

Conclusions from Formulae

The formulae for variation in torque during acceleration shown in equations (13), (14) and (15) have two distinct and separate parts. The first part shows a variation as a function of the applied voltage at any instant and is entirely independent of inertias or rate of acceleration.

Of the first part, the term of equation (13)

$$7.05\,\frac{k_3}{r_3}\,V_0$$

is the total torque of motor No. 3 at standstill just before breakaway. The term T_{L3} is the total torque of final steady state running and is, of course, that resulting from the rolling schedule and strip tension desired. The third term

$$7.05\,\frac{k_3}{r_3}\,Mt\left(1-k_3\,\frac{C}{B}\right)$$

is a function of the rise of voltage and provides a straight line transition from the initial value to the final steady state running value. Also since the flux is constant, the motor current varies in a straight line with voltage.

The condition for zero variation of torque with applied voltage is that the first part of the equation equals zero. In order that the term which is a function of M_t may be zero, it is seen upon inspection of the term $\frac{C}{B}$ that it must be true that

$$(16)\qquad k_3=k_2\,\frac{\sigma_2}{\sigma_3}=k_1\,\frac{\sigma_1}{\sigma_3}.$$

For the remainder of the part to equal zero it is necessary, also considering equations (14) and (15) that

$$(17)\qquad V_0=\frac{T_{L3}\,r_3}{7.05\,k_3}=\frac{T_{L2}\,r_2}{7.05\,k_2}=\frac{T_{L1}\,r_1}{7.05\,k_1},$$

and from equation (16)

$$(18)\qquad T_{L3}\,r_3=\frac{\sigma_2}{\sigma_3}\,T_{L2}\,r_2=\frac{\sigma_1}{\sigma_3}\,T_{L1}\,r_1,$$

and from equation (3)

$$(19)\qquad V_0=i_3\,r_3=i_2\,r_2=i_1\,r_1.$$

This equation (19) states (inertia neglected) that there will be no variation in tension between stands at any *applied voltage*, if the IR drop of each armature circuit is the same at all voltages.

The second part of the variation in torque equation (13) is a function of the rate of acceleration and the inertias involved. The transient term

$$\left[1-\epsilon^{-\frac{B}{A}t}\right]$$

becomes unity in a very short time in any practical case. At t = 0, it is zero and at t = 0.5 to 1.0 sec., it is practically unity.

To make the entire second term zero, it follows that the following equations must hold:

$$(20)\qquad 7.05\,\frac{k_3^2}{r_3}\,\frac{A}{B}-\frac{WR_3^2}{308}=7.05\,\frac{k_2^2}{r_2}\,\frac{A}{B}-\frac{WR_2^2}{308}$$

$$=7.05\,\frac{k_1^2}{r_1}\,\frac{A}{B}-\frac{WR_1^2}{308}=0,$$

or simplifying

$$(21)\qquad r_3\,WR_3^2=r_2\left(\frac{\sigma_2}{\sigma_3}\right)^2 WR_2^2=r_1\left(\frac{\sigma_1}{\sigma_3}\right)^2 WR_1^2,$$

which can be changed to

$$(22)\qquad i_{acc3}\,r_3=i_{acc2}\,r_2=i_{acc1}\,r_1,$$

or the IR drop due to the current required to accelerate each machine's own inertia must be the same for each machine.

Thus, we have the general conclusion that by the selection of resistances by equation (18) and the inertia by equation (21), in that order, a mill may be perfectly balanced for one given set of speed and running load conditions. If this set of speed and running load conditions is changed, once the resistances and inertias are chosen, the balance is upset.

Translation of Torque Variation into Tension Between Stands

The converting of the torque variations into tension variations is done on a horsepower basis. Since the tension at the reel is held constant, all the torques passed by motor No. 3 must change the tension between stands No. 2 and No. 3, so

$$(23)\qquad \frac{T_{p3}\,s_3}{5250}=\frac{P_{3-2}\,FPM_{2-3}}{33{,}000}=\frac{P_{3-2}\,s_2}{33{,}000\,G_2}\,\frac{\pi\,D_2}{12},$$

and, simplifying,

$$(24)\qquad P_{3-2}=\frac{24}{D_2}\,G_2\,\frac{\sigma_3}{\sigma_2}\,T_{p3}.$$

Likewise:

$$(25)\qquad P_{2-1}=\frac{24}{D_1}\,G_1\,\frac{\sigma_2}{\sigma_1}\left[T_{p3}\,\frac{\sigma_3}{\sigma_2}+T_{p2}\right]=-\frac{24}{D_1}\,G_1\,T_{p1}.$$

The two equations for P_{2-1} are given as checks. A positive value of any of the equations means an increase in tension between stands, while a negative value means a decrease in tension.

Some suggestions as to the use of the formulae may prove helpful.

Inspection of equation (13) shows that when t = 0 and V = V_0

$$(26)\qquad T_{p3}=7.05\,\frac{k_3}{r_3}\,V_0-T_{L3},$$

similarly for T_{p2} and T_{p1}. Using these values in equations (24) and (25) the tension variations at breakway voltage are found. This tension variation is, of course, zero at final steady state running voltage and a straight line connects the two points. Thus, it is easy to pick up the value of tension variation at any threading volt-

age. To these tension values are added or subtracted the value due to inertia which is soon constant for a given rate of rise of voltage, since $\epsilon^{-\frac{B}{A}t}$ soon becomes negligible.

PART II

Part I of the analysis dealt with the problem of mill acceleration on the assumption of constant flux in each machine, this value of flux being that necessitated by the final steady state running conditions. This case is easily handled mathematically.

Now we come to the problem of compounding. Suppose the flux changed. What if a series exciter used with an auxiliary shunt field of the main motor were excited from, say, the drop across the commutating field, so that a component of flux were produced in the main motor proportional to motor line current? What effect would this have upon tension?

The procedure is the same as before. However, now

$$\Phi = \Phi_0 + K\,i. \tag{27}$$

Substituting in equations (1), (2), and (3), it is found

$$T_M = 7.05\,Z\left[\frac{V\Phi_0\,r + KV^2 - Z\,\Phi_0^2\,rs - KVZ\Phi_0\,s}{(KZs+r)^2}\right]. \tag{28}$$

Now the torque equation for the system is:

(29)

$$7.05\,Z_1\frac{\sigma_1}{\sigma_3}\left[\frac{V\Phi_{01}\,r_1 + K_1V^2 - Z_1\,\Phi_{01}^2\,r_1\frac{\sigma_1}{\sigma_3}s_3 - K_1\,VZ_1\,\Phi_{01}\frac{\sigma_1}{\sigma_3}s_3}{\left(K_1Z_1\frac{\sigma_1}{\sigma_3}s_3 + r_1\right)^2}\right]$$

$$+7.05\,Z_2\frac{\sigma_2}{\sigma_3}\left[\frac{V\Phi_{02}\,r_2 + K_2V^2 - Z_2\,\Phi_{02}^2\,r_2\frac{\sigma_2}{\sigma_3}s_3 - K_2\,VZ_2\,\Phi_{02}\frac{\sigma_2}{\sigma_3}s_3}{\left(K_2Z_2\frac{\sigma_2}{\sigma_3}s_3 + r_2\right)^2}\right]$$

$$+7.05\,Z_3\left[\frac{V\Phi_{03}\,r_3 + K_3\,V^2 - Z_3\,\Phi_{03}^2\,r_3\,s_3 - K_3\,VZ_3\,\Phi_{03}\,s_3}{(K_3Z_3\,s_3 + r_3)^2}\right]$$

$$= \frac{1}{308}\left[WR_1^2\left(\frac{\sigma_1}{\sigma_3}\right)^2 + WR_2^2\left(\frac{\sigma_2}{\sigma_3}\right)^2 + WR_3^2\right]\frac{ds_3}{dt}$$

$$+\left[T_{L1}\frac{\sigma_1}{\sigma_3} + T_{L2}\frac{\sigma_2}{\sigma_3} + T_{L3}\right].$$

This equation does not lend itself to easy manipulation. However, assuming given values of compounding and neglecting the WR^2 term, it can be readily solved by assuming a motor speed and solving the resultant quadratic for voltage. Also assuming a uniform acceleration, indications of the effect of WR^2 can be obtained.

The authors have made such calculations, the results of which, for assumed 5 and 50 per cent compounding, are shown in Figure 8.

DISCUSSION

PRESENTED BY

F. O. SCHNURE, Electrical Superintendent, Bethlehem Steel Company, Sparrows Point, Maryland.

H. W. NEBLETT, Development and New Design Engineer, Inland Steel Company, Indiana Harbor, Indiana.

A. F. KENYON, Industrial Engineering Department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania.

F. E. HARRELL, Assistant Chief Engineer, Reliance Electric and Engineering Company, Cleveland, Ohio.

T. R. RHEA and M. J. LEDING, Industrial Department, General Electric Company, Schenectady, New York.

F. O. SCHNURE: Assuming a situation that today requires a four or five stand tandem mill for rolling cold strip to tin plate gauge, what delivery speed in feet per minute should be built therein that in the years to come will be considered good practice, all factors of acceleration, motor and generator sizes, cost, and tonnage being considered?

The Maryland Plant has two five stand tandem mills, duplicates except for speed and power. The first is powered by 800 hp. motors with a rated delivery speed of 900 feet per minute which, by overspeeding the motors, has been increased to about 1100, the second by 1000 and 1250 hp. motors with a delivery speed of 1500 feet per minute.

In analyzing the operation of both mills over a period of a month, the faster mill is found to roll only about 12 per cent more steel per hour than the slower unit. If the delivery speed was increased from 1500 to 2000 feet per minute the study shows around 10 per cent increase in capacity with about 40 per cent increase in motor and motor-generator sizes, an important factor. The output of a mill, therefore, is not directly proportional to the speed but is influenced by other factors, such as roll changes, delays, and longer acceleration periods.

The most important consideration, however, is that of off-gauge products during acceleration and deceleration. It is generally thought that gauge is lost as the strip leaves No. 1 stand. If this is figured back to finished strip, the off-gauge on the tail end amounts to about 150 feet and on the front end, including that wrapped around the tension reel, about 180 feet or a total of 330. Actually the off-gauge in practice is only about 65 per cent of this figure.

Since the total off-gauge strip that must be classified and assorted amounts to around 5 per cent of a 5000 pound coil, the importance is apparent of fast

acceleration and deceleration as well as the use of the maximum coil.

Acceleration and deceleration and maximum speed are all directly related to the horsepower which brings us back to the original question.

H. W. NEBLETT: This paper points out quite clearly the presence of tension variation between stands in a tandem cold reduction mill at various speeds and the effect this has on the gauge of the product being rolled. We readily agree with the authors that variation in speed does effect tension and gauge of the strip. Considerable work has been done to correct this condition but to date the problem has not been entirely solved. Threading speeds in tandem mills will produce off-gauge material which either is to be considered as waste or assigned to some other use that can tolerate the heavy gauge material.

By the use of welded coils, thereby obtaining longer coils, the number of threadings for a given tonnage is reduced and the scrap loss decreased. This, however, is only a partial step toward the elimination of off-gauge material.

It is our hope that this paper will further stimulate interest in this important problem and will ultimately result in the elimination of scrap due to threading and low speed operation in tandem cold strip mills.

A. F. KENYON: The paper by Messrs. Rhea and Leding is of considerable interest, and puts into concrete and usable form a number of important factors which must be taken into account if the best performance of the tandem mill drive is to be obtained. Many of these factors have been appreciated and considered for some time, and it is now timely to set them down and draw conclusions for guidance in future installations, as well as to utilize this information wherever applicable to improve the performance of existing mills.

The desirability of selecting motors and making adjustments so that the armature circuit IR drop is the same in each of the motor circuits, was suggested by the performance of early reel drives as compared to the performance of the mill stand drives. The reel motor was usually of relatively small hp. rating, and of wide speed range by shunt field control, so that at its rated full load the armature circuit IR drop was as much as 20 to 25 volts, as compared to 8 to 10 volts drop in the relatively much larger hp. and narrower speed range mill motors. Comparatively the reel WR^2 was invariably much higher than the mill WR^2 and the combination of high IR drop and high WR^2 often resulted in the definitely sluggish response of the reel during starting and acceleration, and thus inability to maintain tension. Practical design limitations do not permit making the low hp., wide speed range reel motors with as low IR drop or WR^2 as the mill motors. However, this difficulty was overcome by the use of a low voltage booster generator, connected in the reel motor armature circuit, and controlled to generate a voltage about equal to the difference between the reel IR drop and the mill IR drop, and thus enable the reel motor to operate at the same counter voltage as the mill motors. Also it was further possible to "jump" the booster generator voltage during the acceleration, so as to force the reel motor to generate higher counter voltage and thus operate at higher excitation and develop the higher torque necessary to compensate for the large WR^2. Such a booster generator was incorporated in the reel drive for a five stand tandem cold reduction mill installed in 1934 and in most of the tandem and single stand mills installed since that time.

We agree whole-heartedly with the authors' recommendation that the mill and reel motor WR^2 be made as low as possible, consistent with economy. This brings to mind a project now being considered in a preliminary way, for the installation of a five-stand mill to be used alternatively for both hot rolling and cold rolling. The hot rolling was estimated to require 2500 hp. and 3000 hp. motors, while the cold rolling would require motors of only about half this capacity. An analysis showed that a 3000 hp., 200/400 rpm. motor, such as used on several hot strip mills, has about 3 times the equivalent WR^2 of even a standard 1500 hp., 300/600 hp. motor, and about 4½ times the equivalent WR^2 of a special low inertia 1500 hp. motor. It was therefore suggested that each stand of the proposed mill be driven by two 1250 hp. or two 1500 hp. motors, these two motors having less than half of the equivalent WR^2 of a conventional 3000 hp. motor.

We note with interest the authors' recommendation for some form of tension indicating device to continuously indicate the strip tension between stands, and thus enable the operators to maintain the tension between safe upper and lower limits, and thereby avoid strip breakage or loss of tension. Such tension indicating devices undoubtedly will be of material assistance in the manual control of the mill, however in our opinion, the ultimate solution will be the use of such devices for the automatic regulation of the mill motors, so as to maintain the desired strip tension, and probably also control gauge by varying the tension between stands.

F. E. HARRELL: I am led to think, in looking at the curves that were presented, that there may be a friction condition in the total bearings on the mill that may have an appreciable effect on the change in the torque from the threading speed to the steady state condition which might explain the departure from the theoretically anticipated condition.

T. R. RHEA AND M. J. LEDING: Mr. Schnure brings up a most interesting question which deserves a thorough analysis. Let us assume, as Mr. Schnure does, that more tonnage is required and that the contemplated 1500 feet per minute cold reduction mill may be the neck of the bottle in the production line. In order to get more tonnage, either the proposed mill should be speeded up or an additional mill should be installed. Which is more economical?

Let us further assume, again with Mr. Schnure, that by stepping up the delivery speed of the contemplated mill from 1500 to 2000 feet per minute (33 per cent increase) the rolled tonnage will go up only 10 per cent, while the capacity of the main drives will go up 40 per cent. This increase of capacity of the main drives will probably result in an increase of

(*Please turn to page 74*)

KNOWN *Iron Ore* RESERVES OF THE WORLD *and* THEIR *Significance*

By CHARLES HART, President

DELAWARE RIVER STEEL CO.

CHESTER, PENNA.

▲ DUE to the great increase in knowledge of iron ore deposits throughout the world, data of this nature is ever changing and of the greatest interest. In this paper a study will be given the latest and most reliable information on the subject.

The significance of the present situation as to iron ore and the adequacy of the world's supply will be discussed, with particular reference to the position of the United States and its permanency in dominating the world's steel industry. A second significance is found in relations existing as between iron and war, and the effects upon national alignments due to wars.

Actual ore—This term is applied to ore now in use or of a quality warranting its use, and upon which fairly accurate information exists as to analyses and tonnages.

Potential ore—Under this heading is classified vast tonnages of ore, which, due to grade and location, are at present unavailable, but which in due time will come into use.

Possible ore—This term will be applied to vast tonnages upon which reliable data as to quality and quantity are simple guesses, and naturally will not come into use until the billions of tons of actual and potential ore have been exhausted.

Iron ore—An iron ore may be described as a rock material consisting of minerals in which iron predominates, and from which this metal may be extracted at a profit. The modification as to profit materially qualifies the extent of iron ore reserves.

Iron has been known to the world for many centuries and its source may be considered a dual one, best considered as celestial and terrestrial.

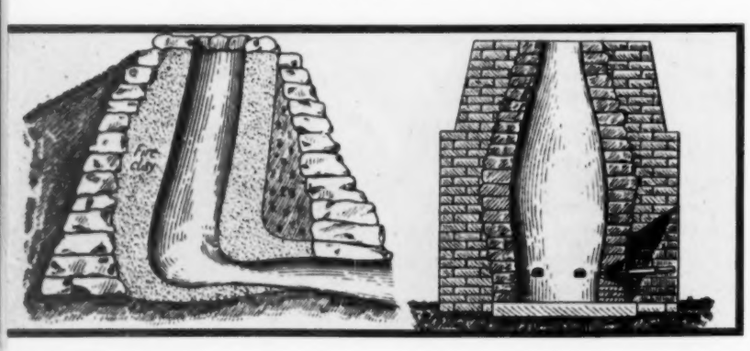
Celestial iron, as the name implies, has its source in the sky and is known as meteoric iron. Knowledge of this "metal from heaven" goes back at least to 6500 years B. C., although its source was not known until 2000 years later—at which time the entire canopy of the sky was assumed to be a solid mass of iron.

Some schools of thought lean to the idea that all iron is of meteoric origin. It is a known fact that 20,000,000 meteorites strike the earth's atmosphere daily, and it is assumed that 100 tons of this material reaches the earth's surface, whereby 40 tons of meteoric iron are added to the world's resources each day. Much of the meteoric iron is not recoverable. due to physical conditions and location. The latter deterrent applies to the Barringer meteor found at Coon Butte in Arizona. Figure 1 well illustrates this unsolved metallurgical and mining engineering problem, although it would seem to be a simple matter to recover this low carbon nickel steel.

The analysis shown gives credence to the thought that the earliest forms of iron were in every way equal to some of the best alloy steels of the present day. This mass of nickel iron, estimated at 10,000,000 tons with a present day value of $600,000,000, is an engineering problem of the greatest interest, and one promising great financial return to the fortunate solver.

Terrestrial iron, upon which the world's steel industry depends, is found almost entirely in chemical union with other elements and it is to these compounds that this paper is devoted.

FIGURE 2—Pre-Roman furnace for the smelting of iron, one of the early methods of working iron ore.



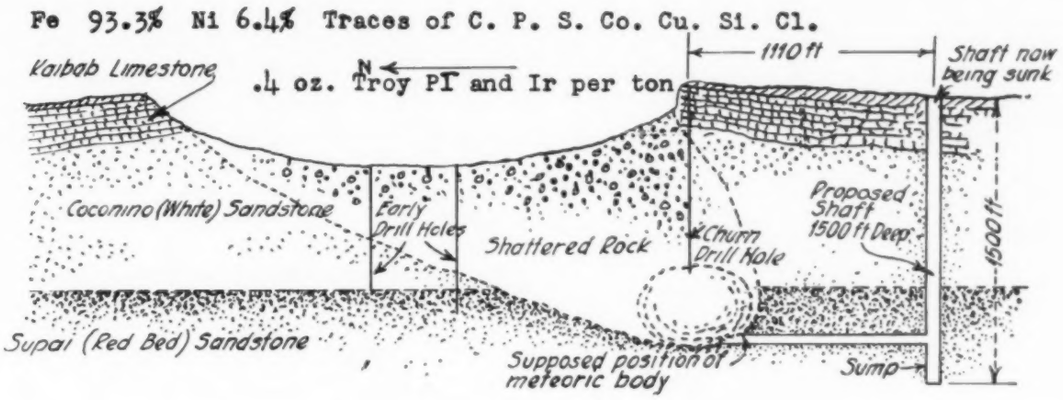

Fe 93.3% Ni 6.4% Traces of C. P. S. Co. Cu. Si. Cl.
Kaibab Limestone
.4 oz. Troy Pt and Ir per ton
1110 ft
Shaft now being sunk
Coconino (White) Sandstone
Early Drill Holes
Shattered Rock
Churn Drill Hole
Proposed Shaft 1500 ft Deep
1500 ft
Supai (Red Bed) Sandstone
Supposed position of meteoric body
Sump

FIGURE 1—Diagram of Barringer meteor at Coon Butte, Arizona.

It is definitely known that iron was revealed to the world by the burning of the forests on Mount Ida about 1500 B. C. Whether, or not, this was the first knowledge of terrestrial iron is undeterminable, due entirely to lack of communication in early days. Records indicate early smelting of iron at Halstadt in Austria, and also conscious working of iron in China and Japan at least 500 years earlier than the Mount Ida forest fire. However, the burning forests produced a metal as yet little known to man, and no doubt all our present methods of recovery of iron are referable to that conflagration. The open fire method accompanied by much forging was the immediate outgrowth of this discovery. The transfer of the open fire to hill tops and then its inclusion in crevices in hill sides were but logical steps in efficiency, and were steps to the natural draft on mountain tops and forced draft furnaces in the valleys.

The pre-Roman furnace shown in Figure 2 and the Catalan forge shown in its highest development in Figure 3 are respectively outgrowths of the earliest methods of working iron ores, and are the forerunners of our modern blast furnaces.

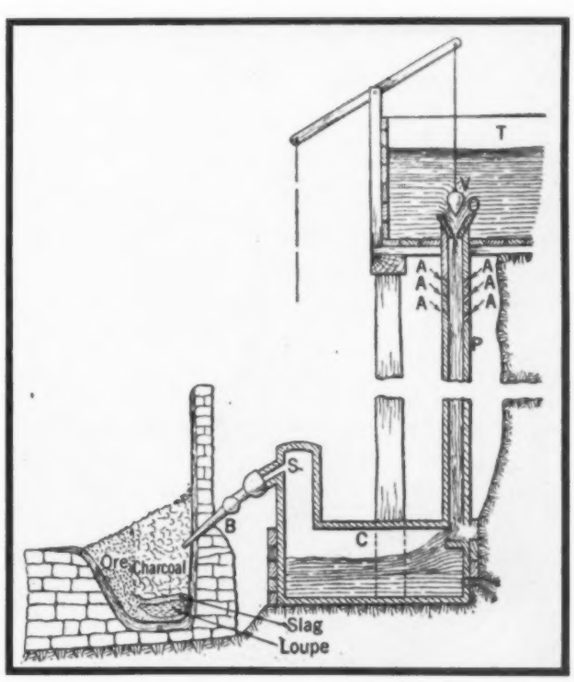
These early devices are of general interest, but their greatest interest lies in their inefficiency whereby vast tonnages of scoria resulted. This material was so rich in iron that most of it was used in coal fired blast furnaces at a later date. The scoria from the Forest of Dean operations kept twenty furnaces in operation for a period of three hundred years. As late as 1921 piles of this material up to 25,000,000 tons and running 60 per cent in iron were offered from Italy.

The iron ore reserves of the world have at all times been the subject of investigation and controversy. Pliny, the Elder, after a trip to Spain early in the first century of the Christian era, made the much quoted statement that "Iron ores are to be found almost everywhere", and further stated that "There is a great dissimilarity in iron ores". The centuries since Pliny's time have yielded a knowledge of enormous reserves which amply confirms both of his statements.

In 1910 the eleventh International Geological Congress convened in Stockholm, Sweden. This meeting was devoted to a study of iron ore reserves, and all nations were invited to participate. The results of this meeting as to the known reserves in iron ore are shown in Table I.

Reference to this table indicates clearly that ninety-nine percent of the known ores were located in Europe

FIGURE 3—The Catalan forge represents one of the higher developments of the early methods of iron production.



and the Americas, and that of Americas' quota, eighty-six percent was credited to the United States. A table will be shown later covering the world knowledge as of 1938, with further consideration of the relative position of the United States, in which the greatest interest lies.

The reserves within the United States, together with adequate and well located coal reserves indicates this nation's position in competition for world dominance in steel production. In this connection the eight other outstanding deposits of the world are of interest, in that they may compete with the United States or may supplement that nation's resources. These deposits are:

1. Minette ore of Central Europe
2. Ores of the United Kingdom
3. The Ukraine and Ural ores of Russia
4. The magnetites of Lapland
5. Ores of India
6. Wabana ore of Newfoundland
7. Laterites of Cuba
8. The vast reserves of Brazil

It is apparent that the first five of these eight deposits cannot aid the United States, but will continue to be highly competitive for world domination. The Wabana ore undoubtedly will, as time goes on, be most helpful. If and when the metallurgical problems involving the laterite ore of Cuba are solved, large shipments of that ore to the Atlantic seaboard may be expected. Brazil may be expected to furnish the United States with even greater tonnages of ore than Cuba, if and when transportation is commercially possible. In the meantime the United States will continue to use its own reserves found in the north and south, and will supplement these ores with importations from relatively small but workable deposits.

TABLE I

WORLD SUMMARY OF ORE SUPPLY 1910

	Actual Reserves		Potential Reserves	
	Ore Million tons	Iron Million tons	Ore Million tons	Iron Million tons
Europe	12,032	4,733	41,029	12,085+
America	9,855	5,154	81,822	40,731+
Australia	136	74	69	37+
Asia	260	156	457	283+
Africa	125	75	Many thousands	Many thousands
	22,408	10,192	123,377+	53,136+

THE UNITED STATES

The greatest deposits of iron ore found in the United States are located in the Lake Superior district. The tonnage of actual ore was placed at 3,500,000,000 tons by Hayes in 1908 and by Kemp in 1910. This figure has its use and shows the change in definition for ore, in that by 1938 it was estimated that our reserves have dwindled to 1,324,862,000 tons. This figure is based upon Mr. Zapffe's letter of May 13, 1938, with allowance for ore mined since the date he mentions. This estimate is little more than half the 2,200,000,000 tons of actual ore credited to the Lake Superior District by the U. S. Tariff Commission.

EXCERPT FROM MR. ZAPFFE'S LETTER OF 5/13/38

"As of May 1, 1936, the Minnesota Tax Commission engineers set up 1,257,108,284 tons for Minnesota. That estimate includes a lot of marginal ore, much that we call Reserve Ore today not marketable, and considerable as concentrates calculated from crude ore-material of various types but mainly wash-ore, plus a little of the jig-ore type.

"As of January 1, 1937, the Michigan Commission set up a total of 154,032,944 tons for Michigan.

"For Wisconsin we usually take 6,000,000 tons as a comparable figure.

"Summarizing:—

1,257,108,283 tons
154,032,944
6,000,000

1,417,141,227 tons

Reference to Table II. shows the regularity as to analysis with an average iron content of 51.50 percent, and emphasizes the excellence of these hematite and limonite ores.

TABLE II

ANALYSES OF UNITED STATES ORE

Year	Tons	Iron	Phos.	Sil.	Mn.	Moisture
1936	44,745,754	51.45%	.091%	8.62%	.81%	10.92%
1935	28,214,056	51.44	.093	8.93	.79	10.75
1934	21,841,382	51.49	.087	8.93	.76	10.66
1933	21,455,174	51.85	.090	8.96	.71	10.47
1932	3,552,575	52.16	.099	9.05	.68	9.92
1931	23,281,333	51.53	.087	8.60	.80	10.84
1930	46,698,554	51.33	.095	8.70	.82	10.92
1929	65,443,546	51.18	.100	8.48	.80	11.24
1928	54,045,941	51.15	.099	8.43	.85	11.37
1927	51,730,711	51.19	.105	8.60	.84	11.31
Av.		51.50%	.095%	8.75%	.80%	10.84%

These Lake Superior ores are not bettered by any large competitive production in the world. Forty percent of the shipments have been beneficiated by one process or another, but as yet sixty percent of this beneficiation is accomplished by crushing and screening.

Exhaustion of the Lake Superior ores by 1955 was intimated as late as 1929. Beneficiation of hematites

and magnetites was not considered in those estimates, nor years like 1932 were not visioned. Consequently the 72,000,000,000 tons of potential ore were given little consideration when such claims were made, although this figure was used by Kemp in 1910.

At the Stockholm meeting, Dr. Joseph Richards took strong exception to Kemp's figures and insisted that the Lake Superior district should be credited with 250,000,000,000 tons of ore with an iron content between the limits of 35 percent and 50 percent. Dr. Richards also took the position that this tonnage should be included in the actual reserves of the United States. None of the above estimates include the quartzites with an iron content approaching 30 percent, in tonnage variously placed up to 250,000,000,000 tons depending upon the depth of drilling. Under present definitions for iron ore, such reserves can only be rated for use far in the future and therefore come under the heading of possible ore.

According to Mr. Zapffe, Minnesota holds ninety percent of the actual ore reserves of the Great Lakes district. The Mesabi range produces seventy to eighty percent of all lake shipments and it has produced since being opened in 1892 more than 1,000,000,000 tons of ore. An outstanding operation on this range is the Hull-Rust Mine. Figure 4 shows the extent of this open pit, while Figure 5 gives some interesting data as to the work involved.

These illustrations emphasize the value of the Mesabi Range and indicate low mining costs with maximum production, whereby an annual output of 60,000,000 tons is at all times possible. However, ore mining in Minnesota is sadly handicapped by unfair taxes, which amount to practically one dollar per ton on the ore shipped. The ranges of the Great Lakes district are capable of shipping 72,000,000 tons per year, providing transportation is available and a demand exists for the ore. Nowhere in the world does as great efficiency exist in the mining, transportation and smelting of iron ores.

FIGURE 4—View of the Hull-Rust Mine, one of the outstanding operations on the Mesabi range.

EASTERN MAGNETITES

The tax situation in Minnesota may have many repercussions which may lead to basic alterations in the present mode of steel production, whereby the magnetites of New York and New Jersey will assume new importance.

In 1937 the Republic Steel Corporation in the outstanding deal in steel circles for that year, assumed control of the Witherbee-Sherman properties at Port Henry, New York, by a long term lease. Wet processes for concentration will be installed and it is expected that 1,000,000 tons of sinter will be available annually, running 70 percent in iron and less than .035 percent in phosphorus. The advantages of this material are found in increased production and a greatly reduced coke consumption.

Reserves of magnetite in the two states—exclusive of the 250,000,000 tons of ilmenite containing 20 percent titanic acid—are conservatively estimated at 2,500,000,000 tons for New York and 800,000,000 tons for New Jersey. These low grade ores should yield in due time 1,650,000,000 tons of sinter approaching the analysis given for the material expected from the Port Henry operation.

Time does not permit a detailed discussion of the steps in magnetic separation of iron oxides. Reference, however, is due to the early and successful efforts of Wetherill and the commercial failure of the outstanding trials by Thomas A. Edison. Of more recent date and of far more importance are the highly successful de-

velopments in this line by the Alan Wood Steel Company working on their New Jersey magnetites. In this connection special attention is called to the epoch making work done by Messrs. Whiting and Agnew of that company. The details and results of this work have been published and need no further comment here. The word fayalite is given a wider definition than is expressed in the formula Fe_2SO_4, upon which Whiting places a wider construction; and Harrison suggests an even wider term, "silicates". By a reduction of the silica in the concentrate, the resultant sinter assumed excellent qualities and a difficult metallurgical problem was solved. This solution will bring into use vast tonnages of low grade magnetites in the United States and elsewhere. On the East Mesabi, a tonnage of these low grade magnetites estimated as high as 5,000,000,000 tons lie dormant, in spite of Jackling's courageous efforts to work them.

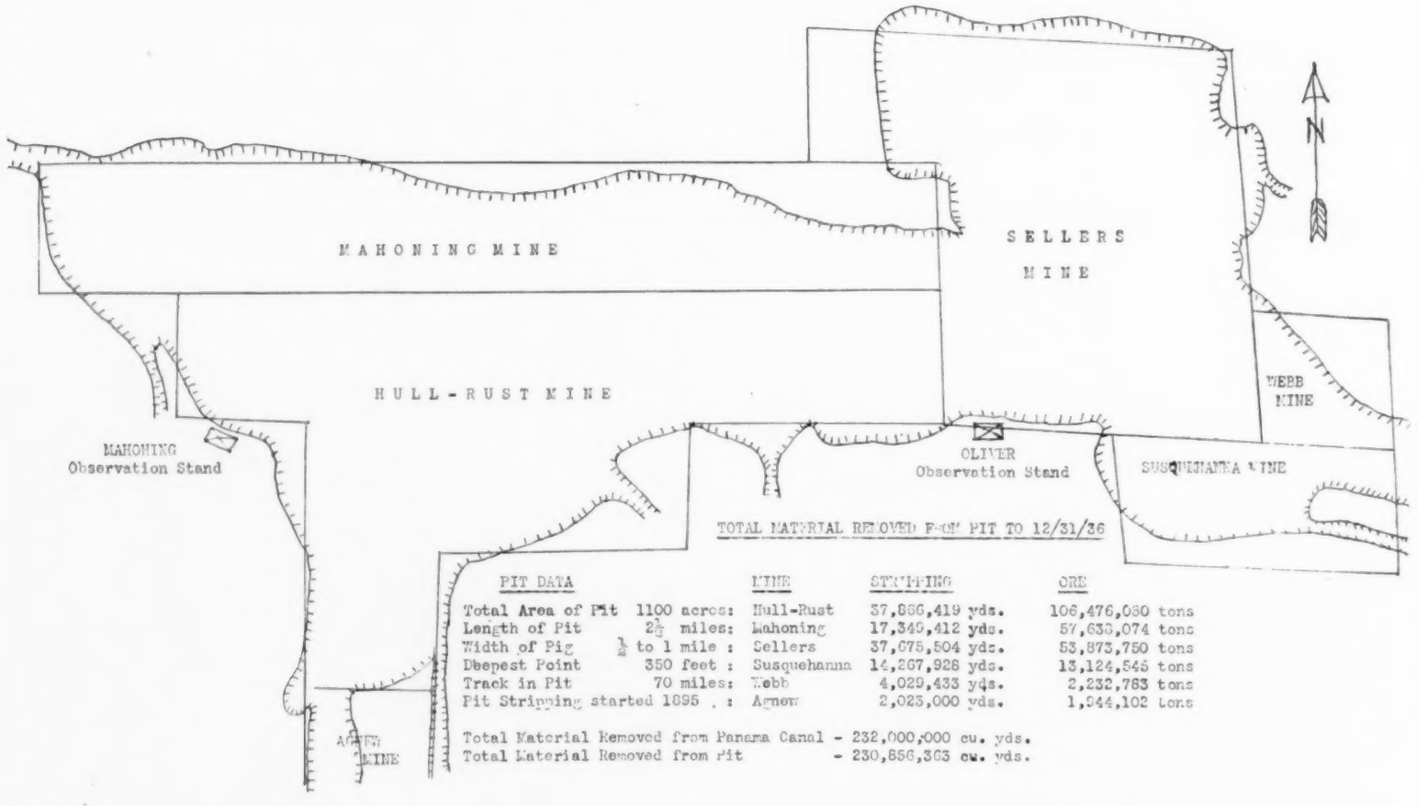
It is evident that the successful solution of the fayalite problem will increase the reserves of the United States by 4,500,000,000 tons of high grade furnace material. On account of the richness of this sinter it will be possible to mix it with leaner ores, so that its usefulness in the steel industry may be extended at least a hundred years. However, there are a number of unknown quantities in this problem that make any prediction hazardous.

While on the subject of magnetites, the only worthwhile iron ore deposit in the State of Pennsylvania should be noted. This is located at Cornwall and reserves are variously placed at 40,000,000 to 60,000,000 tons, plus other undisclosed and possible deposits. The ore as found approaches 33 per cent in iron. Concentration and sintering by the Greenawalt process produces a material practically double that iron content with low phosphorus sulphur and copper percentages. Shipments in excess of 1,000,000 tons annually are available. This mine was first opened about 1735 and is no doubt the oldest active ore mine on the American continent.

In the northeastern section of the United States it is estimated that there are deposits of Clinton ore to the extent of 750,000,000 tons, hematites amounting to 4,000,000 tons and limonites in excess of 25,000,000 tons.

Before turning to the southeastern ore deposits, reference is made to the 250,000,000 tons of black band ore which is found mostly in western Pennsylvania and eastern Ohio, with minor tonnages in West Virginia and Kentucky. This ore had considerable use prior to the discovery of the Lake Superior deposits, to which they have temporarily succumbed due to quality. The

FIGURE 5—The extent of the Hull-Rust Mine is shown by this diagram, giving operating data of the immediate vicinity.


MAHONING MINE
SELLERS MINE
HULL-RUST MINE
WEBB MINE
MAHONING Observation Stand
OLIVER Observation Stand
SUSQUEHANNA MINE
AGNEW MINE
N
TOTAL MATERIAL REMOVED FROM PIT TO 12/31/36
PIT DATA
Total Area of Pit 1100 acres:
Length of Pit 2½ miles:
Width of Pit ½ to 1 mile :
Deepest Point 350 feet :
Track in Pit 70 miles:
Pit Stripping started 1895 . :
MINE STRIPPING ORE
Hull-Rust 37,866,419 yds. 106,476,080 tons
Mahoning 17,349,412 yds. 57,638,074 tons
Sellers 37,675,804 yds. 53,873,750 tons
Susquehanna 14,267,926 yds. 13,124,545 tons
Webb 4,029,433 yds. 2,232,763 tons
Agnew 2,023,000 yds. 1,044,102 tons
Total Material Removed from Panama Canal - 232,000,000 cu. yds.
Total Material Removed from Pit - 230,856,363 cu. yds.

furnaces then in existence in the Mahoning and Shenango Valleys turned to the use of the Lake Superior ores, but Youngstown's position in the steel industry is attributable to the early use of these band ores.

SOUTHEASTERN UNITED STATES

This district is rich in ore and coal, and this situation is the basis of the healthy and growing steel industry which centers in and around Birmingham, Alabama. The close proximity of coal, ore and flux serves to make this condition in nature ideal for iron production. The relatively low iron content of these ores is overcome by low assembly costs, to the extent that the cheapest pig iron in the Americas is produced. Analyses of the principal ore used in this district are shown in Table III.

The Clinton or red ores are classed as soft and hard. This does not mean physical hardness, but refers to the presence or absence of lime, and is comparable with hard and soft water. Further economy in the use of these ores is indicated in largely self-fluxing mixtures.

The red ores exist in large quantities, but reserves applicable to the present status may be placed at 1,500,000,000 tons, supplemented by 25,000,000 tons of limonite. These figures represent only a small portion of the total reserves of this southeastern section. Eckel states that this section is credited with 1,000,000,000 tons to 5,000,000,000 tons of Clinton ore, to which may be added 250,000,000 tons of brown ore. His findings are most interesting as set forth in "Iron, Chromite, and Nickel Resources of the Tennessee Valley Region". Figure 6 illustrates his ideas as to the relation existing between the iron reserves of eastern United States and electric current from the Tennessee Valley operation, which is available for smelting these ores.

TABLE III

ANALYSES OF PRINCIPAL ORES USED IN THE BIRMINGHAM DISTRICT

	Iron	Silica	Alumina	Phosphorus	Lime
Hard Red Ore	35.00	12.00	3.00	.30	17.00
Soft Red Ore	45.00	17.00	5.00	.27	3.00
Brown Ore	48.00	13.00	4.00	.45	2.00

This illustration implies that lake ores, if required, could be used for electric smelting in the Tennessee Valley. The great quantities of southern ores that are not so closely located to fuel, as those in the Birmingham district, are also available. It is evident that electric energy is transmittable at comparatively low costs.

The coastwise area extending from Massachusetts to Louisana, and shown as a potential consuming district of foreign ores is to be noted. However, it is axiomatic that the only companies that can exist by depending upon foreign ores are those having completely integrated plants. In such cases the ore demand is sufficiently large and regular to justify ownership of foreign mines with control of all transportation. Only under such conditions can foreign ore be depended upon as a year in and year out supply for any Atlantic seaboard plant.

The white area indicated is devoid of iron blast furnace operations today, save the highly favored plants in the Birmingham district.

Carbonate ores approaching 100,000,000 tons are found in this southeastern section, and are possible reserves. At least 150,000,000 tons of magnetites may be included in the possible column, due to recent improvements in beneficiation processes.

WESTERN UNITED STATES

A large part of this great territory is without notable ore reserves.

Missouri has rather well defined deposits, from which shipments were made years ago but they long since gave way to ores from the Great Lakes District.

Texas, undoubtedly, has the largest deposits found west of the Mississippi River. The ore is found in two basins, and although the ore is of the same origin, these basins show two ores of widely different character due to the nature of the original greensand deposit. The original glauconite, an under water deposit, is found in place but in varying degrees of metamorphosis. The north basin, due to the texture of the greensand, was

FIGURE 6—Map showing the relation existing between iron reserves of eastern United States and electric current from the Tennessee Valley operation.

transformed through siderite to limonite. The steps are noted in their chemical composition, in which glauconite is found to approach 50 per cent in silica. 25 per cent in iron oxides and 6 per cent in potash. The siderite contains 85 per cent of ferrous carbonates with silica, alumina and ferric oxide each under 5 per cent. The resultant limonite may be credited with 50 per cent metallic iron and 12 per cent combined water, in addition to usual percentages of silica and alumina. The south basin for reasons already noted yields a bright yellow ore in which the iron content drops to 45 per cent and is friable in nature.

These two basins are credited with 150,000,000 tons of actual limonite, to which it is safe to add 1,000,000,000 tons of potential ore. Possible ore found in glauconite and siderite exists in unmeasured quantities.

Glauconite as a possible iron ore may be new in iron ore discussions. However, this does not eliminate it from consideration for it is a mineral of wide distribution. The principal American deposit is found in New Jersey. According to E. C. Eckel, the total greensand of this state may have required 250,000,000,000 tons of ferric oxide in its formation. It is most regrettable that nature did not act in New Jersey as it did in Texas, whereby inexhaustible deposits of brown ore would have resulted, an oversight that man-designed processes have not been able to remedy.

PACIFIC COAST AND ROCKY MT. STATES

United States Government water power plans in the west have awakened interest in the iron ore deposits of that section, similar to the Tennessee Valley Authority activities in the South. This interest has resulted in a survey of the western situation by Messrs. Hodge and Miller under the direction of the War Department. The following data is taken from their reports and is particularly applicable to such deposits as are available to the Grand Coulee Dam operation.

A maximum reserve of 700,000,000 tons may be credited to the Pacific states, half of which is found in California alone. As to the Rocky Mountain section, available information is even less dependable but it is safe to place actual ore at 200,000,000 tons, with a potential reserve twice that figure.

Total reserves for the United States reach astounding figures in that actual ore, according to the U. S. Tariff Commission, exceeds 10,000,000,000 tons—and even Russia concedes this country 9,850,000,000 tons. Recent developments in ore preparation have materially changed our actual reserves, in that potential ores in Hayes' and Kemp's reports are now firmly in the actual column. The Tariff Commission's figure is considered the best authority.

Potential ore, and by that it is understood to apply to ores which may come into use within the next hundred years, are placed at 84,400,000,000 tons. When endeavoring to estimate possible ore and by allowing due credit to the quartzites beneath the Mesabi and possible recovery of iron from glauconite deposits, we obtain a figure too vague for publication.

Future sources of supply for iron ore may be found in neighboring states which have abundant resources, but are without adequate fuel or demand for steel. Of such possibilities Cuba is the nearest.

CUBA

Southern Cuba has been nearly exhausted of ore in that only about 8,000,000 tons remain. The principal deposits are found in five fields on the north coast of the island. Actual ore in these deposits is estimated at 3,000,000,000 tons, to which, on United States Government authority, three times that figure may be added for potential reserves. Due to chemical analysis, annual shipments do not greatly exceed 100,000 tons. These Cuban ores result from the laterization of serpentine rock which occurs in humid climates, with or without bacterial action. Table IV. shows analysis of the original rock and the analysis of the resultant laterite ore.

The commercial analysis represents to some extent the 12,000,000,000 tons of laterite ore in Cuba and fairly well indicates the chemical composition of additional tonnages throughout the world equal to this figure. Several processes for the beneficiation of these ores have been developed and patented, but as yet no commercial results have been obtained. The solution of this problem will result in heavy shipments of ore from Cuba to our Atlantic seaboard.

NEWFOUNDLAND

In addition to indefinite but large deposits of ilmenite, Newfoundland has one of the largest of the eight great ore reserves of the world in the Wabana mine The ore was first exposed on Bell Isle, and has been found to extend a great distance under the sea, which indicates original deposition in a marine basin.

TABLE IV
ANALYSES OF COUNTRY ROCK AND IRON ORE, MOA BAY, CUBA

	Serpentine	Iron Ore		
Fe_2O_3		66.90%	Commercial Analysis	
FeO	8.55%		Mayari Laterite	
SiO_2	37.29	1.71	Dried at 212°F.	
Al_2O_3	1.33	11.60	Average of 19 Samples	
TiO_2		.14		
Cr_2O_3	.28	2.65	Iron	45.67%
NiO		.60	Silica	6.26
P_2O_5	.07	.07	Alumina	10.64
MnO	trace	.80	Chromium	2.80
CaO	.29		Nickel	
MgO	36.53		Phosphorus	.008
K_2O	trace	2.38	Comb. Water	11.59
Na_2O	.39			
Water	15.27	12.51		

This ore offers an interesting mineralogical feature in that it runs nearly one quarter in chamosite, which is reflected in the rather high silica and alumina percentages in the commercial analysis, as shown in Table V.

The company can mine 2,000,000 tons per year, and in 1938 the production was 1,680,213 tons of ore. A ready market was found for 1,121,000 tons in Germany. In that country operations using one-half Wabana and one-half Swedish magnetites show results comparable with American standards. Next to Germany the Wabana ore finds its greatest use in the company's own furnaces at Sydney, Nova Scotia, and in 1938, 495,846 tons were shipped to that point. It is apparent that next to Sydney, ocean freights from Newfoundland to the Atlantic seaboard are the lowest, inasmuch as the records show large imports of Wabana ore in past years. It is to be expected that the United States at a future date will look to these reserves for a considerable tonnage.

Four accredited engineers have placed the figure 3,500,000,000 tons for actual ore; and with certain limitations as to minability, Eckel estimates a total reserve of 10,000,000,000 tons.

News of a recent disclosure of an iron ore deposit in Labrador estimated to contain 1,000,000,000 tons has just been published. The ore is Bessemer in grade, and shows an iron content of 40 to 45 per cent.

TABLE V

ANALYSES OF NEWFOUNDLAND WABANA ORE

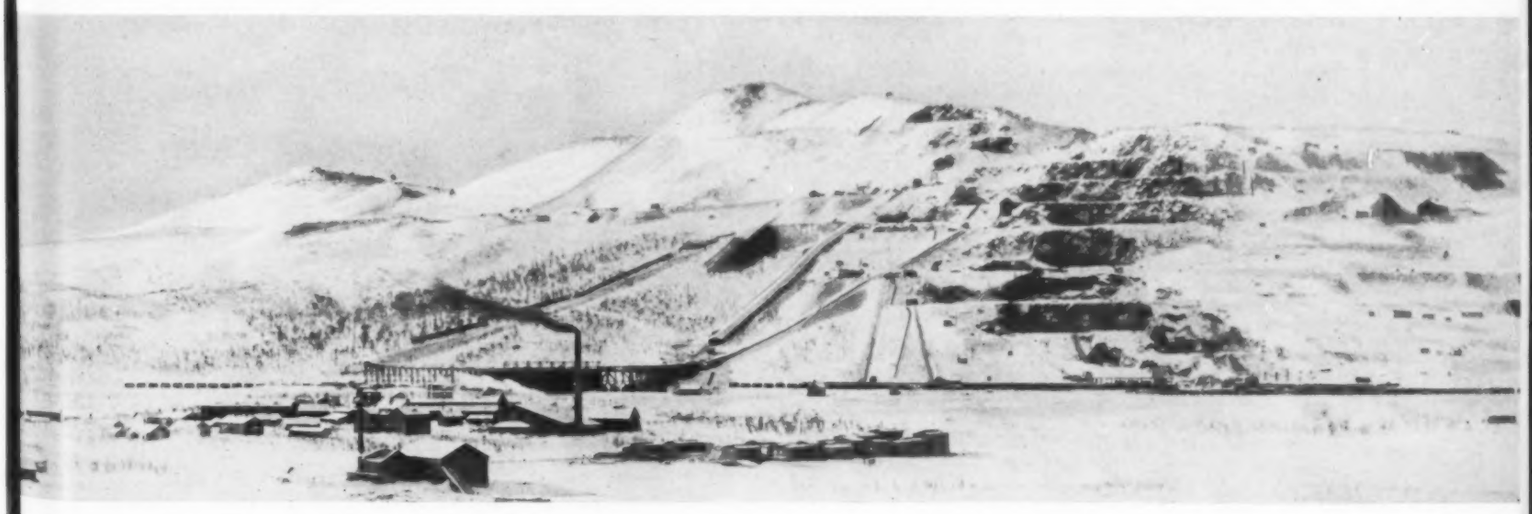
Mineral Content			Commercial Analysis	
Chamosite	SiO_2 . . . 25.64%	23.06%	Iron	51.50%
	Al_2O_3 . . . 19.75		Silica	12.00
	FeO 39.74		Phosphorus	.90
	MgO . . . 2.98		Lime	3.00
	H_2O . . . 11.89		Sulphur	.053
Ferric Oxide		59.94%	Alumina	4.55
Siderite		5.51	Magnesia	.65
Silica		5.42	Manganese	.12
Calcium Phosphate		4.40	Titanic Acid	.35
Calcium Carbonate		.94	Combined Water	2.50
Manganese Dioxide		.29	Carbon Dioxide	2.50
Titanic Acid		.35		
Iron Pyrite		.09		
		100.00%		

MEXICO

It is quite natural that estimates pertaining to iron ores in Mexico should be indefinite, in that this country is lacking in adequate coal reserves necessary for a steel industry of national magnitude. Their interest in copper, oil and the precious metals has contributed to this lack of reliable figures on iron ore. The 1910 estimate placed total actual reserves at less than 60,000,000 tons, which was increased by Government authority to 242,798,000 tons by 1918. A complete check upon the part of our War Department places total measured actual ore at 1,750,000,000 tons, with a potential reserve of only 660,000 tons. Due to the lack of prospecting it is safe to assume that behind the known reserves there remain immense deposits of possible ore as yet undiscovered. The totals above given are from the Hodge report and the reserves classify themselves as to whether they are available or unavailable for the proposed Oregon project.

The outstanding deposit in the first class, and in fact in all of Mexico, is the Las Truchas mine in Michoacan. This ore lies exposed and within easy reach of an excellent harbor. The deposit is reported to contain

FIGURE 7—Kiirunavaara Iron Ore Mountain, in Lapland, is the largest Swedish ore operation.



950,249,984 metric tons of hematite corresponding to analyses shown in Table VI.

Iron Mountain in Durango is credited with 200,000,000 tons. This mine is now in operation.

All the known ores of Mexico seem to be of high grade, but undeveloped for reasons already stated.

CENTRAL AMERICA

Nicaragua and Panama are each credited with 25,000,000 tons of ore, and Honduras with 200,000,000 tons of excellent magnetite.

WEST INDIES (OTHER THAN CUBA)

Records show 41,000,000 tons for Haiti, and 430,000,000 tons for Porto Rico, both being lateritic in nature.

CANADA

After giving consideration to this great and friendly neighbor's resources in iron ore, data for the known ore of North America will have been completed.

Although this Dominion is larger than the United States, it is relatively poor in known iron ore reserves and this lack of knowledge is due entirely to climatic conditions. From available statistics the actual ore of Canada may be placed at 300,000,000 tons, to which it is possible to add 100,000,000 tons due to recent exploration of a new deposit in the M-shaped Steep Rock Lake in Atikokan. This ore is hematite in grade and runs 55 per cent in iron and less than .012 per cent in phosphorus.

There are two outstanding ore deposits in the Province of Ontario. The New Helen mine is owned by the Algoma Steel Corporation, Ltd., with furnaces at Sault Ste. Marie. The mine is located twelve miles from Michipicoten Harbor and is estimated to hold at least 100,000,000 tons of siderite ore high in manganese and sulphur, with iron at 33 per cent. This mine is about to be put into operation and the rate of production is expected to reach 300,000 tons of finished product.

The Moose Mountain magnetite deposit exceeds 100,000,000 tons of low grade ore showing 45 per cent silica and 35 per cent metallic iron.

Both of these ores are low in phosphorus and both require beneficiation, which would result in two blast furnace materials ideal for mixture, as shown by analyses in Table VII.

The advantages that could be derived from such a mixture are easily apparent; and results from a mixture of siderite such as the New Helen with magnetic concentrates are well shown in German efforts recently published by the Kaiser Wilhelm Institute, of Dusseldorf.

TABLE VI

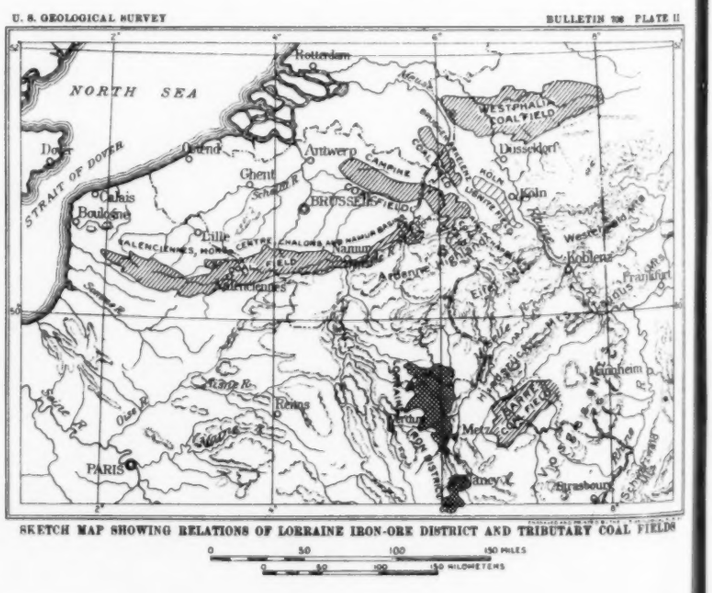
ORE ANALYSES, LAS TRUCHAS, MEXICO

Iron	63.37%	65.71%	63.39%	65.75%	66.16%
Phosphorus	.060	.040	.043	.061	.058
Manganese	.02	.06	.04	.01	.04
Silica	6.50	3.85	6.30	3.98	4.05
Alumina	.38	.46	.67	.38	.43
Lime	.08	.05	.14	.13	.03
Magnesia	.07	.11	.11	.20	.18
Sulphur	.08	.05	.14	.13	.03
Ignition loss	1.88	1.38	1.87	1.63	1.35

The Ontario Government is ready to pay a bounty of two cents per unit on all ore produced in that province. This arrangement results from a situation wherein practically all the ore used in Ontario originates in the Lake Superior district. Inasmuch as at least a part of these lake ores are subject to state taxes per ton equal to the Ontario bounty, it would seem that early development of the Canadian mines would be highly desirable. This situation is further emphasized by the fact that for the ten year period ending with 1937, the average annual shipments into Canada were at the rate of 1,250,000 tons, which include Wabana ore received at Sydney, Nova Scotia. For the same period production of ore in Canada was less than 2,300 tons per year.

In order to consider Canada as a supplier of ore to the United States in the future, it is clear that unex-

FIGURE 8—Map showing portions of France and Germany, representing about 50,000 sq. miles, containing 86,000,000,000 tons of coal and 7,000,000,000 tons of iron ore.



pected discovery of reserves in the southern part of the Dominion is necessary.

Various other provinces contribute the 100,000,000 tons included in the actual figure and not found in the two deposits already mentioned. These deposits are not large in that no one of them exceed 20,000,000 tons.

It is assumed that the North American deposits are of the most vital importance to the steel industry in the United States, which gives the necessary excuse of detailed discussion of these reserves.

The actual ore of the continent is placed at 22,357,-000,000 tons, with potential reserves of 100,433,960,-000 tons, which is made up from reliable reports. With due allowance for many reported iron bearing areas which lack the necessary third dimension of depth, the possible and eventual use of the Lake Superior quartzites, the New Jersey glauconites, and the vaguely known deposits of inferior ore, it is easy to conjure up a possible reserve figure that in the centuries to come may assume commercial value.

TABLE VII
PERCENTAGE ANALYSES OF CANADIAN ORES

New Helen Sinter		Briquettes—Moose Mountain Magnetites	
Iron	50.000	Iron	63.030
Phosphorus	.020	Silica	6.300
Silica	7.500	Sulphur	.013
Alumina	4.250	Phosphorus	.030
Manganese	3.000	Alumina	.950
Lime and Magnesia	11.000	Lime	1.850
Sulphur	.060	Magnesia	1.510
Arsenic	.001	Manganese	.070

TABLE VIII
PERCENTAGE ANALYSES IN BRAZILIAN ORES

	Iron	Phos.	Sil.	Al.	CaO	MgO	Sul.	Mn.	H_2O	Ig. Loss
Itibara	69.21	.010	.37	.28	.18	.16	.007	.16	.12	.10
Canga	61.21	.123	1.49	4.01	.03	.05	.040	.55	....	5.84
Bedded Hematite	67.45	.036	.31	1.51	.06	.03	.017	.29	....	1.26
Minaes Garaes	67.08	.051	.54	1.41	.03	.01	.012	.26	1.65	1.60

	Iron	Phos.	Moisture
Burnier	62.31	.112	.90
Sabara	69.26	.007	...
Itibara	69.06	.015	...

SOUTH AMERICA

The vast deposits of Brazil are one of the world's outstanding ore reserves, but due to high freight rates to port of shipment and rather high ocean freights due to lack of return cargoes, only relatively small shipments have been made. The excellence of the ore is shown in Table VIII. In fact due consideration to the excellence of these ores emphasizes the seriousness of the transportation problem.

The Itabara ore is the result of the transformation of an iron bearing quartzite known as Itabarite. This ore is found in the state of Minaes Garaes and in tonnages the deposits exceed 3,500,000,000 tons. Total reserves for this state are placed at 13,000,000,000 tons, most of which is extremely low in phosphorus and runs between 65 and 70 per cent in iron. The Canga ore is a conglomerate, also found in Minaes Garaes, but is lower in iron. Reserves in this particular ore are estimated at 2,000,000,000 tons. Large deposits of crumbly Itabarite occur, in which the iron content is 59 per cent. The physical condition is such that practically all of it passes a screen with 100 meshes to the inch.

Well authenticated reports indicate fairly large deposits of magnetite, some of which contains appreciable percentages of titanic acid.

Total actual reserves for the United States of Brazil are placed at 7,000,000,000 tons, and total ore having an iron content of 50 per cent or better at 15,000,000,000 tons. In addition to the iron ores there are deposits of manganese ore of good grade and of fairly large proportions. Shipments to the United States amount to as much as 200,000 tons in good years.

Lack of fuel and the absence of any great demand for steel products in South America has delayed iron mining to any great extent.

CHILE

This country, in spite of the fact that it is located on the west coast of South America, and shipments to the United States must stand the tolls through the Panama Canal, is the only consistent producer of ore on that continent. The ores in Chile are not equal to the best of the Brazilian ores, but due to their location at points convenient for ocean shipping they hold the better position. The principal shipper is the Bethlehem Steel Company, who mine the El Tofo ore under lease. This ore containing about 58 per cent of iron is shipped in the largest freighters extant with cargoes up to 24,000

tons, and is received at Sparrows Point, Maryland. Due to favorable location and efficient management, 1,500,000 to 2,000,000 tons are shipped from this mine annually. R. M. Miller looks upon this Tofo ore as being desirable for use in the proposed Government electric smelting operations in Oregon.

TABLE IX
PERCENTAGE ANALYSES OF MINETTE ORES

	Iron	Silica	Alumina	Lime	Magnesia	Phos.	Ig. Loss
Red	40.4	9.6	5.5	8.2	.5	.70	14.00
Gray	31.8	6.6	2.3	19.0	.5	.70	22.00
	38.6	7.90	5.5	11.2	...	.63	20.00
	40.6	6.7	3.2	11.0	1.2	.78	19.04
	39.9	6.0	4.9	11.0	1.1	.77	19.40
	39.2	6.2	6.1	9.1	1.1	.78	18.70
Average	36.0	6.7	4.4	12.3	1.0	.73	19.83
Yellow	36.0	7.0	4.2	9.8	1.5	.30	.....
Brown	24.0	16.6	6.5	8.6	2.0	.60	.....
Black	39.7	15.1	5.2	5.9	.5	.70	14.00

VENEZUELA

Various abortive attempts have been made to ship ore from the Imataca mine on the Orinoca River. These attempts have met with failure due to the unnavigable conditions on that river. The Imataca ore is found in the Imataca Mountains and according to analysis is of excellent quality with physical conditions quite like the Itabara. The reserves are apparently small in that estimates claim only 10,000,000 tons for this mine.

Another deposit in this area contains about 15,000,000 tons of black hematite. This ore is noteworthy in that selected samples show metallic iron in excess of 71 per cent. Piocoa in the Colon claims holds 5,000,000 tons of ore running 50 per cent in iron. The actual ore for Venezuela is estimated at approximately 50,000,000 tons with potential reserves placed at twice that figure.

PERU

The Marcona deposits located ten miles from the ocean are credited with 500,000,000 tons of hematites with an iron content of 60 to 65 per cent. To this tonnage may be added 64,000,000 tons of ore running 68 per cent in iron found in Junin.

The remaining countries of South America are credited with reserves of less than 50,000,000 tons. Total reserves for South America, with due allowance for incomplete surveys, may be placed at 8,230,080,000 tons of actual ore with potential reserves approaching 6,800,000,000 tons.

EUROPE

After a more or less careful survey of the ores available for use in the United States, the European situation stands out as next in importance. It is possible to find on this continent the greatest threat to American supremacy in steel production. This is especially true due to coal and ore reserves in France and Germany, which will be fully shown in the proper place in this paper The European nations will be taken into consideration in the order of importance as to ore reserves coupled with their consumption, a premise which automatically brings the reserves of France into the picture.

FRANCE

We will consider the Minette ore of France first on the list, due to the extent of these deposits and their importance in international relations. The earliest operations were so insignificant that the name Minette, meaning "little mine", was given in derision. This ill repute has since been lived down in that ore approaching 7,000,000,000 tons in extent and responding to the analyses shown in Table IX are attributed to this, the largest single deposit of iron ore in Europe.

This ore is oolitic in nature and the bonding material may be either siliceous or calcareous, as reflected in the analyses shown. In general the mixture of these ores as used is self-fluxing, in that ten parts of the limy ore is used with one part of the high silica grade. The relatively high phosphorus content bespeaks for a pig iron suitable for use in the Thomas Gilchrist process, and with the introduction of this process in 1878 this ore came into its own.

At the close of the Franco-Prussian War in 1871 Germany, as the victor, exacted the territory of Alsace Lorraine in addition to an indemnity of 5,000,000,000 gold francs. The transfer of that territory passed nearly one-half of the Minette reserves to Germany, under whose control they remained until after the World War when the Treaty of Versailles returned Alsace Lorraine to France. France, therefore, controls all the Minette ore with the exception of about 270,000,000 tons credited to the Duchy of Luxembourg.

Total ore reserves of France are placed at 12,000,000,000 tons, of which seventy-five per cent may be included in the actual column. The deposits of Normandy include 2,000,000,000 tons, and those of Brittany may be placed at 750,000,000 tons.

In 1938 France produced 33,000,000 tons of iron ore with an iron content averaging 30 per cent. 18,000,000 tons of the ore produced was for home consumption and 9,000,000 tons were exported to Belgium and Luxembourg.

TABLE X

PERCENTAGE ANALYSES OF REPRESENTATIVE SWEDISH ORES

	Iron	Sil.	Al.	Mn.	Lime	MgO.	Sul.	Phos.
Kiiruna "A"	68.25	2.24	.54	.10	.86	.98	.026	.021
Kiiruna "B"	67.46	2.68	.45	.07	1.02	.83	.026	.053
Kiiruna "C"	68.36	1.72	.36	.06	.99	.73	.010	.236
Kiiruna "C[II]"	66.14	1.91	.40	.10	2.65	.77	.013	.755
Kiiruna "D"	60.30	2.47	.35	.12	7.05	1.23	.015	2.06

SWEDEN

The iron ore reserves of Sweden consist largely of rich magnetites and they no doubt represent the outstanding deposits of this grade of ore in the entire world. The best operation is at the Kiirunavaara mine in Lapland. This huge mountain of iron shown in Figure 7 is one hundred miles north of the Artic Circle, and represents Sweden's largest mining operation. In spite of climatic conditions this is an open air operation in which modern electric machinery is used. Ninety per cent of the ore mined is produced in this manner.

The Kiirunavaara ores vary greatly in phosphorus content and respond to the analyses shown in Table X.

The Luossavaara mine is closely associated with the Kiirunavaara operation and is of interest due to the high phosphorus content, as shown in Table XI.

It is pretty well established that this group of mines, of which Kiiruna is the leader, contain more than 2,250,000,000 tons of ore with an iron content exceeding 65 per cent.

The Gellivare group is also located in southern Lapland and contains well over 500,000,000 tons of magnetite. In chemical properties this ore so closely resembles the Kiiruna ores that it seems unnecessary to show their analyses.

In central Sweden, which abounds in high phosphorus magnetites and some low phosphorus hematites, it is safe to place reserves at 200,000,000 tons. The magnetites are exported and the hematites are used in domestic operations.

In southern Sweden scattered deposits of ore are found, of which Taberg Mountain is the most important with a reserve placed at 50,000,000 tons averaging 32 per cent in metallic iron and 7 percent in titanic acid.

Sweden's total reserves may be placed at 3,000,000,000 tons, made up largely of rich megnetites.

The Lapland ores are dominated largely by the Loussavaara-Kiirunavaara Company, in which private capital and the Swedish Government are equal partners —although it is possible these mines will be nationalized by the year 1947. In the meantime shipments amounting to about 12,000,000 tons per annum are permitted. This figure approximates the average exports over the last two years. Further leniency on the part of the Swedish Government brought about by the great demand for these ores will permit an additional tonnage of 6,000,000 tons from the Lapland mines and an additional 600,000 tons from Grangesberg by October 1, 1940.

Due to a lack of adequate coal supply it is not expected that Sweden will ever be a contender for world dominance in steel production, but will at all times be a factor in this competition as a supplier of ore to countries not so well provided with ore.

TABLE XI

PERCENTAGE ANALYSIS OF LOUSSAVAARA "R" ORE

Metallic Iron	37.60
Silica	13.96
Alumina	1.62
Manganese	.09
Lime	15.53
Magnesia	.94
Phosphorus	4.63
Sulphur	.02

RUSSIA

Recent data furnished by the Soviet Union would indicate that Russia holds more iron ore than any other European country, and it is evident from the following that they have a better knowledge of iron ore reserves and other mineral resources under the Soviet Rule than obtained under the rule of the Czars:

U. S. Soviet Russia 1937–1938

Area		14,776,346 sq. mi.
Population		209,421,885
Actual iron reserves	—1910	921,000,000 tons
	—1938	9,850,000,000 tons
Potential reserves	—1910	1,000,000,000 tons
	—1938	10,600,000,000 tons
Coal reserves	—1910	233,985,000,000 tons
	—1938	1,654,361,000,000 tons

Ninety per cent of the ore reserves are found in

Russia proper, while ninety-one per cent of the coal occurs in Siberia. Due to publicity of the five-year plan the magnetites of the Ural Mountains stand out in prominence. Although these deposits are vast they do not represent Russia's greatest reserves, nor do shipments from the Urals represent more than twenty-five per cent of that country's production.

Russia's most modern furnaces are devoted to smelting these ores from the Urals. In this operation coal from Kutznetzk is used, at which point furnaces and steel plants are also operated. This operation involves a haul of 1427 miles from coal to furnaces. It is needless to say that an operation of this character could only exist in a country devoid of private capital and where cost sheets do not prevail.

The pre-Soviet estimates as to reserves were about as follows:

Krivio Rog (Curved Horn)—400,000,000 tons of ore with an iron content of 60 per cent plus, and phosphorus at minus .030 per cent.

Kertch—500,000,000 tons of yellow and brown ore with an iron content of 35 per cent to 42 per cent and phosphorus approaching 1 per cent. The physical condition of these ores causes action in the furnace similar to that caused by the Mesabi ore in its worst days, due to carbon deposition.

Central Russia—350,000,000 tons of ore, mostly unexplored and little used.

The Urals—400,000,000 tons consisting of magnetites with an iron content of 60 per cent; and hematites in much smaller tonnages.

The total of these reserves approaches 2,300,000,000 tons and checks well with the total ore indicated for pre-Soviet times, as shown above, and is comparable with the 1938 claims of more than 10,600,000,000 tons, as published by the U. S. Bureau of Mines, excerpt which is as follows:

> "Russia: Iron Ore Reserves: The reserves of iron ore were estimated at 10,600,000,000 tons as compared with 9,850,000,000 tons in the United States. This estimate excludes the enormous reserves of low grade ore such as the Kursk and Krivoi Rog quartzites which together amount to 241,300,000,000 tons".

These estimates were supplied by the U. S. S. R. Geological Survey, but it is questionable whether these quartzites may be classed as an iron ore.

The Krivoi Rog district, with reserves now placed in excess of 1,000,000,000 tons, is the largest producer of iron ore in spite of the fact that Magnitogorsk is given the greater publicity. Of the 28,000,000 tons of ore produced by Russia in 1938, about two-thirds came from the former district and 6,000,000 tons from the latter, one-half of which was smelted in the new blast furnaces at the point of origin and the balance shipped to Kutznetzk. The balance of the ore produced was made up of miscellaneous lots from less productive

TABLE XII

ORE RESERVES OF THE UNITED KINGDOM 1922

	Actual	Probable	Possible	Total
Jurassic	1,212,000,000	2,177,000,000	420,000,000	3,809,000,000
Carboniferous	1,049,000,000	1,247,000,000	5,423,000,000	7,719,000,000
Hematites	45,000,000	90,000,000	.....	135,000,000
All others	.....	16,000,000	76,000,000	92,000,000
	2,306,000,000	3,530,000,000	5,919,000,000	11,755,000,000

(No ore containing less than 20 per cent metallic iron was included in this survey.)

TABLE XIII

PERCENTAGE ANALYSES OF JURASSIC ORES IN NATURAL CONDITION

	Iron	Mn.	Sil.	Al.	Lime	Mag.	S.	P.	Water
Northamptonshire	32.5	.24	14.7	6.1	2.7	.04	.10	.60	15.2
Cleveland	28.1	.41	11.8	10.2	4.7	3.5	.26	.47	6.8
Leicestershire	25.2	.23	10.9	8.0	9.6	0.6	.11	.25	16.4
Oxfordshire	24.0	.27	10.2	7.6	12.2	0.6	.06	.23	15.6
No. Lincolnshire	22.7	.96	8.1	5.1	18.2	1.0	.16	.31	10.7
Kent—Dover	33.0	...	15.0	....	9.0	...	.05	.45	0.0

mines, among which shipments of less than 1,000,000 tons per year from West Siberia are noteworthy.

The potential ore already mentioned is low grade and runs less than 30 per cent in metallic iron, and much of it should be classed as possible in quality. This tonnage is comparable with a like situation in the United States where iron bearing materials of like grade far exceed those credited to Russia.

THE UNITED KINGDOM

The ore reserves of the United Kingdom as of 1922, and by her own admission, were approximately 12,000,000,000 tons, as shown in Table XII.

The Jurassic ore shown in Table XIII is oolitic in nature and is akin to the Minette ore of France. The same variation in matrix is indicated in the analyses shown.

The black band and clay band ores of carboniferous formation predominate in the 1922 estimate. Dr. Louis in preparing the 1910 figures for the Stockholm estimate, placed total reserves of the United Kingdom at 39,500,000,000 tons and stated that 35,000,000,000 tons could be classed as band ores. He further stated that forty-four per cent of these ores were to be found in South Wales alone. In his estimate all ores containing less than 25 per cent metallic iron were eliminated. Table XIV shows the analyses of these two ores.

TABLE XIV

PERCENTAGE ANALYSES OF BLACK-BAND AND CLAY-BAND ORES

	Black-Bands	Clay-Bands
Ferric Oxide	.20	0.0
Ferrous Oxide	40.50	37.02
Manganese Oxide	1.00	1.60
Silica	4.72	8.61
Alumina	3.60	5.60
Lime	4.24	8.29
Magnesia	1.89	3.07
Carbonic Acid	29.39	29.71
Phosphoric Acid	.82	1.29
Sulphur	.28	.27
Iron Sulpide	.24	.23
Bitumen	14.00	2.03
Water	1.41	.75
Metallic Iron	31.13	28.96

The analyses are averages made up of a great many results, in which the metallic iron varies as between 20 per cent and 40 per cent in the raw ore. These band ores are roasted before being charged into the furnace. It is noteworthy that in the case of the black band ore there is present sufficient bitumen for this roasting.

The Jurassic and band ores represent ninety-eight per cent of the British Isles' reserve. Although these ores are cheaply mined, their action in blast furnaces coupled with relatively high costs for pig iron has acted as a deterrent to their use. The chemical and physical properties of these ores have been the contributing factor in this phase of the industry. The recent work done by two of our outstanding engineering firms is too well known to require any further discussion. We might add, however, that their results are far reaching and are being adopted by many countries who are in like predicaments.

In the hematite industry, which originated in England, is found the excuse for importations of iron ore, and this explains the rather large imports from Spain in years gone by. The Spathic and Rubio ores originating near Bilboa have contributed to that port's prominence in the trade. England's own reserves of hematite may be placed at 108,000,000 tons in Cumberland and 22,000,000 tons in Lancashire. These ores range from 50 per cent to 60 per cent in iron and .005 per cent to .012 per cent in phosphorus, which indicates the phosphorus in the resultant steel by the acid Bessemer process is within the range of .04 per cent and .06 per cent.

There are other deposits of various grades but their total tonnage does not exceed 100,000,000 tons and comment is unnecessary.

The changes in iron metallurgy in the British Kingdom are easily understood, in that the trend in steel making is to the basic process—a trend which materially increases domestic production with an increased demand for ore from Newfoundland, Sweden and Africa. These changes are reflected in the present situation in that eighty-two per cent of the open hearth steel is made in basic furnaces, and about six per cent of the steel made is by the acid Bessemer process. Total steel capacity is about 14,000,000 tons and blast furnace capacity may be placed at 13,000,000 tons. Record breaking production of steel in 1937, placed at 12,980,000 tons, called for an ore consumption of 21,000,000 tons, one-third of which was imported.

GERMANY

Germany is next in line with ore reserves totaling 5,038,050,000 tons. This figure includes 878,400,000 tons acquired within the last few months in the territory recovered by Germany. Total reserves are relatively small per capita as compared with Sweden, France, Russia and Great Britain, but this apparent handicap is offset by importations. Due credit for Germany's position in steel production should be given to her excellent coal reserves, which are the best in Europe. In 1938 she maintained second place in the world's industry with an output of 23,500,000 tons of steel, produced from 13,000,000 tons of domestic ore and approximately 23,000,000 tons of imported ore, and an unknown tonnage of scrap.

In an effort to make the best of a difficult situation as to iron ore reserves, Germany has turned to the 1,500,000,000 tons of Salzgitter ore found in the Weser district. In the main this ore consists of a high phos-

phosphorus conglomerate with an iron content averaging 30 per cent and carries 12 per cent moisture. The ore deposits are now being subjected to a careful survey, which as to accuracy is comparable with the exploration of the Mesabi reserves of Minnesota. It is expected that these mines will produce 20,000,000 tons annually, of which 6,000,000 tons will be shipped to the Ruhr and the balance smelted in the Weser district without the use of scrap. It is understood, however, that six of the thirty-two furnaces contemplated were transferred to the Danube district after Germany acquired Austria last year.

It is interesting to note in the 1910 report to Stockholm that the actual and potential ore claimed for Germany did not exceed 4,000,000,000 tons—but the vague term "sehr erheblick" seems to have stood for vast tonnages of reserves. The Salzgitter Ilseder claim in 1910 did not greatly exceed 250,000,000 tons, and a like figure was assigned to the chamosite deposits in Thuringia. It is therefore worthy of note that in spite of the fact she lost the Minette reserves, Germany proper now has as much ore as she claimed to have in 1910.

THE BALKAN STATES

The territory which includes the Balkan and neighboring states still free from German control hold a total ore reserve of 649,450,000 tons, most of which is of inferior grade and made up of chamosite, oolites, siderites, scoria and limonites.

Poland has by far the greatest tonnage in reserve. Two-thirds of the Bulgarian deposits amounting to 1,500,000 tons consist of scoria. Greece contains at least 200,000,000 tons of laterite which is comparable with the Cuban ores already discussed. This central European situation at the present time holds the center of the stage.

BELGIUM-LUXEMBOURG

This combination is particularly interesting in that the Thomas Gilchrist process and the Minette ore of Luxembourg produce a low cost steel in Belgium which finds a ready market in the United States. Production of Minette ore in Luxembourg runs consistently between 3,000,000 tons and 6,000,000 tons per year, and is supplemented by imports largely from France. In the year 1937 exports of steel to the United States from Belgium exceeded 136,000 tons, or more than forty per cent of total imports of steel from Europe.

ITALY

Italy is lacking in ore and fuel, which to some extent is made up by the use of electric power and importations of relatively high percentages of iron ore, and supplemented by the use of pyritic residues to the extent of 30 per cent of all the material charged into the blast furnaces operated in that country. With the exception of the 25,000,000 tons of scoria already mentioned, Italy's total iron ore reserves do not exceed 17,000,000 tons. Recent reports furnished to the United States Consular Service indicate rather large reserves in Abyssinia, but too remote for exploitation.

SPAIN

This country is credited with 1,327,000,000 tons of reserves—one-half of which exceed 52 per cent in iron, and all of it may be classed as comparatively low in phosphorus. Before the World War average annual production of iron ore in Spain was at the rate of 8,000,000 tons, one-half of which was shipped to England, six per cent direct to Germany and ostensibly thirty per cent through Holland to Germany, and minor shipments to the United States and other countries. During the war shipments were cut in half and since then, due to labor trouble and civil war shipments have been so greatly reduced that in 1938 only 1,850,000 tons were produced, and this figure represents a great increase over years just prior to 1938.

NORWAY

During the late war Norway made an effort to benefit their Sydveranger ore by use of a wet process. One cargo was shipped, but it was found impossible to secure boats for additional shipments due to the extreme mobility of the sloppy concentrate. Norway's total reserves may be placed at 1,750,000,000 tons, ninety per cent of which must be recovered from ores showing 30 per cent to 35 per cent metallic iron, some of which are high in titanic acid. Considerable tonnages of pyrite are also found in this country.

HOLLAND AND DENMARK

These two countries together with Belgium are without significance in iron ore reserves.

TOTAL RESERVES

The entire continent of Europe may be credited with 32,608,010,000 tons of actual ore and 13,993,050,000 tons of potential reserves. If Russia's claim on quartzites is allowed, together with other low grade minerals found throughout Europe, the figure for possible ore approaches 290,000,000,000 tons and represents a reserve not yet usable and therefore a far distant probability.

AFRICA

It is not to be expected that any country in the African continent will be a contender for a dominating position in the world's steel industry. This situation is due to a lack of a market—reflecting as it does a dearth

of steel mindedness on the part of the majority of the inhabitants. Therefore, Africa will continue to furnish ore to the steel producing countries of Europe, and in increasing tonnages.

The 1910 estimate placed reserves at 125,000,000 tons, most of which was found in the Atlas Mountains. This estimate was increased to 150,000,000 tons of actual ore by 1922, with a like tonnage of potential ore. Since the latter date much exploratory work has been done on reserves in other parts of the continent. In Sierra Leone actual ore in excess of 150,000,000 tons has been found, and excellent ore in excess of 1,000,000 tons annually may be expected from this deposit alone. In 1910 no numerical values were placed upon African deposits other than those in Algeria and Tunis. The balance of the continent was credited with "considerable", "many thousands" and "enormous" tonnages.

The present situation due to exploration calls for an estimate of 1,410,000,000 tons of actual ore, with a vague and questionable potential reserve of 8,000,000,000 tons in the southern parts of the continent. Much of this should be classed as possible due almost entirely to its geographical location. To this figure may be added 1,000,000,000 tons of laterite ore to be found in French West Africa.

Liberia has ceased negotiations with the Noord Europe Maatrchappy looking towards the development of their ore reserves, which are believed to be extensive and should be classed as possible. To this same classification may be added the 6,000,000,000 tons of ore just reported from Cairo as being recently discovered in Egypt, and an equally vague tonnage of laterite in excess of 2,000,000,000 tons in Morocco.

The Union of South Africa with an area of about 472,347 sq. mi. is apparently rich in actual ore as well as potential reserves, as indicated below:

(a) High grade	112,000,000 tons
(b) Medium grade	5,900,000,000 tons
(c) Titaniferous ore	2,114,000,000 tons
(d) Low grade potential	2,286,000,000,000 tons

The estimates included in this paper give no value to the (d) figures in spite of their enormity. If this tonnage were spread out over the entire Union, a stratum of two and one-half feet would result, which is a bit thick.

As to consumption of iron ore in Africa, the principal producer of steel is the Iscor plant at Pretoria, from which point 233,000 tons of steel were shipped in 1937. Investigations are now in progress looking towards an increase in steel production in this part of Africa.

ASIA

This continent with its adjacent islands make up a vast territory, with a population concentration practically fifty per cent greater than that of the United States. Due to the lack of steel mindedness on the part of the Asiatics, we find a relatively low per capita consumption of steel and a corresponding lack of interest in iron ore reserves.

INDIA

This Empire has the greatest steel production and the best showing as to iron ore reserves, which are placed at 3,000,000,000 tons of actual ore averaging better than 60 per cent metallic iron, and 17,000,000,000 tons in the potential class. These reserves are further augmented by enormous unmeasured deposits of laterites, banded quartzites, noduled clay ironstones and ilmenites.

Present knowledge as to quality and quantity of coal reserves does not show an encouraging condition for steel production. However, a thorough examination is now being made under the direction of the Geological Survey of the Empire.

The largest single steel operation in the whole British Empire is found at Tatanagar, 153 miles from Calcutta, where the Tata Iron and Steel Company has blast furnaces and steel plants of modern design.

JAPAN

This island contains approximately 100,000,000 tons of actual ore and there are also great and unmeasured reserves of magnetic sands. The actual ores may be classed as magnetites, micaceous hematites, red hematites and limonites. In analysis they show the usual characteristics of iron ores in general. The brown ores have a tendency to run high in sulphur.

Immense deposits of magnetic sands estimated at 500,000,000 tons are found throughout Japan. They have been worked for centuries as they were the earliest sources of terrestrial iron on this island. This material must be washed before working, and when so treated two principal materials result. One is adaptable to direct steel making, and the other easily smelted in a blast furnace.

The relatively low per capita reserve in iron ore explains Japan's activities in acquiring control of the deposits of Manchuria, as well as their interest in all ore reserves bordering on the Pacific Ocean. Japan is the strongest and most progressive political division of the Far East, and iron is essential to its program.

The Fengtien Province of Manchuria alone was credited with 1,000,000,000 tons of ore, mostly magnetic with a metallic iron content between 30 per cent and 35 per cent. In 1921 Tenegren assigned to China approximately 400,000,000 tons of actual ore and nearly 600,000,000 tons of potential ore—and stated that ninety per cent of China's ore reserves were commercially controlled by Japan, a grip that was greatly tightened with the seizure of Manchuria in 1932.

It should be noted that a well known American engineering firm is now acting as advisor to the Japanese Government in the matter of smelting the low grade magnetites of Manchuria, and that in this study the recent development in this country as to Fayalite plays an important part.

Japan should be credited with great scientific advancement as reflected in work done on their magnetic sands, and also in diverting the laterites of the Pacific Islands to useful purposes.

Japan's ambitious program of extension indicates a desired pig iron production of 6,500,000 tons by the year 1945, as against present capacity of 2,260,000 tons. The present production is made possible by the use of twenty-five per cent of scrap and importation of large tonnages of iron ore. The plan for greatly increasing

present pig iron capacity would seem to predict an increasing interest in ores foreign to that country, as is already noted by more or less recent news pertaining to ores of Australia, the Phillipine Islands and Mexico.

CHINA

Tenegren has given fairly accurate figures on Chinese ore reserves, and due to the situation in Manchuria it is safe to place China's present total reserves at 100,000,000 tons. In 1910, T. T. Read also stated that China held that amount of ore running better than 60 per cent in iron. A 1938 estimate by arithmetic places China's reserve at 250,000,000 tons, with an annual output of 1,000,000 tons. The present situation is too clouded by war to permit of any prediction as to China's future position in world steel competition.

Up to this point the outstanding countries of Asia have been discussed, and little of practical interest is to be found in the remaining territory. Siberia may be credited with less than 1,000,000,000 tons of reserves, Arabia with 500,000 tons, French Indo-China with 25,000,000 tons, and Trans-Caucasia with 18,000,000 tons. This completes the Asiatic countries with definite claims for iron ore resources. The remaining countries are without reserves or the claims are for less than 100,000 tons.

Therefore, the actual known ores of Asia may be placed at 4,600,000,000 tons with a potential reserve of 19,000,000,000 tons—to which possible ore with a rating of enormous should be added. The extent of this possible ore is lacking due to incomplete prospecting, in which climatic and other geographic conditions have played an important part.

OCEANIA

The numerous large and small islands comprising Oceania are found in the Pacific Ocean, and the waters in which they are found covers approximately one-fifth of the earth's surface.

The outstanding deposits of iron ore are found in Australia and the Phillipine Islands.

AUSTRALIA

This island is many times larger than any of the others and should be credited with 919,931,000 tons of actual ore, 550,000,000 tons of which is found on the Koolan and Cockatto Islands in Yampi Bay. The excellence of these ores is shown in Table XV.

These ores have been the subject of news items as negotiations were nearly completed, whereby a Japanese mining company would have had the right to mine 1,000,000 tons per year for a period of twenty-five years. However, the negotiations were discontinued, due no doubt to England's reactions to the present undeclared war on China.

TABLE XV

PERCENTAGE ANALYSES OF KOOLAN ISLAND, YAMPI BAY ORE

Iron.....	66.480	64.910	66.910	60.900	68.270	41.430
Sulphur...	.070	.040	.050	.010	.020	.010
Phos.....	.062	.012	.014	.050	.009	.008
Water....	.....	.....	.17	3.500	.240	.120

PHILIPPINE ISLANDS

The reserves found in the Surango Province of Mindanoa Island are placed at 430,000,000 tons. These ores are lateritic in nature and in origin and analyses closely resemble the laterites of Cuba. The lack of fuel and no real demand for steel products places these islands as suppliers of iron ore. Japan has had negotiations with the Philippine Government looking toward the purchase of the Surageo fields, which by the way are now a Government reservation. On the advice of an American engineer these negotiations fell through and sale of the ore to Japan as it is mined was substituted. Japan is the natural purchaser and in 1938 that country took 650,000 tons of ore from the Philippines. Magnetite and hematite ores are also found on these islands, and in unknown tonnages.

It is entirely within reason to place the reserves of actual ore at 500,000,000 tons with an equal tonnage of potential ore—to which can be added the two estimates doubled for the possible reserves. This assumption is based upon data pertaining to laterite ore found in Cuba.

NEW ZEALAND

Reserves of standard grade ore are less than 65,000,000 tons and are augmented by 5,374,000 tons of actual reserves in magnetic sands. When concentrated, these sands yield a material with an iron content in excess of 58 per cent, low in phosphorus and sulphur, but with deterrent titanium percentages. It is thought that reserves of actual ore for New Zealand and its mandatory possessions may be placed at 70,000,000 tons, to which a potential figure of 10,000,000 tons may be added. The figure for possible ore is not great. New Zealand has no outstanding ore consuming plant.

DUTCH EAST INDIES

Magnetite reserves are placed at 50,000,000 tons, to which 1,000,000,000 tons of laterite ore may be added. Japan as usual has been alive to the situation, and imports from Jahore in 1935 exceeded 1,500,000 tons; and under a new concession shipments to Japan from

Treganu will exceed 1,000,000 tons annually. Due to conditions existing on these islands, it is reasonable to place possible reserves at 5,000,000,000 tons, largely lateritic in nature.

BRITISH NORTH BORNEO

Limonite ore to the extent of 25,000,000 tons is credited to this British possession, and it is said this ore averages 56 per cent metallic iron.

Data on the many other islands making up Oceania is meager and adds nothing to estimates already mentioned. Therefore, reserves of actual ore are placed at 2,059,000,000 tons, potential ore at 1,300,000,000 tons and possible reserves at 1,000,000,000 to 5,000,000,000 tons.

SUMMATION

The situation as of 1938 is therefore as follows:

	Actual (tons)	Potential (tons)
Europe	32,608,100,000	13,993,050,000
America	22,357,000,000	100,443,960,000
Oceania	1,950,325,000	1,300,000,000
Asia	4,600,000,000	19,000,000,000
Africa	1,410,000,000	9,000,000,000
	62,925,425,000	143,737,010,000

A most excellent resume by Kuhn in 1926 placed total actual reserves of the world at 57,811,923,000 tons, with potential ore at 167,662,940,000 tons. Variations in these estimates may be ascribed to new discoveries and to differences in the construction placed upon the terms potential and possible. The latter classification is most elastic. If recognition were given to the quartzites and glauconites of America and to Russia for claims of potential ore, together with the low grade ores credited to the Transvaal, there should be no question as to the permanency of the steel industry. Nor is any value placed upon the deposits of magnetic sands found in many places, although they are successfully used in Japan.

Another great possible reserve is found in the iron, copper and sulphur combination known as pyrites, pyrrhotite, chalcopyrites and the many other variations found in this class. We may look upon these as secondary reserves in that the iron residues are only usable after the copper and sulphur have been removed, and therefore the extent to which they are available depends upon the world demand for these two elements. A reserve of 150,000,000 tons of pyrites is credited to Spain in the Rio Tinto deposits. Appreciable tonnages are also found in Norway, Italy, Mexico, the United States and Canada. An outstanding deposit is reported from Honduras, underlying hematite ore with an iron content of 50 per cent. The proportions of the two materials do not seem to be defined, but the aggregate tonnage is more than 4,000,000,000 tons based upon dimensions given.

The data assembled has been obtained from sources believed to be the most reliable in existence as to world reserves. Although some of the estimates are the roundest of round figures, they are believed to have equal value with those denoting greater exactness as to units. Many reports show area only, and without the necessary third dimension of depth. To such reports no credit is assigned.

SIGNIFICANCE

The total reserves shown above should be assuring and create the feeling that in the actual and potential ores there is to be found an adequate supply of iron ore for many centuries to come. The ores resulting with the cheapest net cost for steel are naturally the first that will be exhausted. With this exhaustion it will then become a matter of competition whether the richer potential ores now too far distant, or the poorer ores near at hand shall replace the depleted ores. In this competition the same rule as to lowest cost will be the governing factor. Beneficiation, which is already a factor, should throw the preference to the low grade ores, in that they are already in production in sufficient tonnage to tend to put off the evil day when the better ores now in use are gone. World consumption of iron ore for the 25-year period 1913–1937 was at the average rate of 133,199,955 gross tons per year. With due allowance for an increased population and increased consumption of steel, there is nothing in these rather startling figures to cause alarm as to the all time sufficiency of the world resources.

The situation in the United States is equally assuring when full consideration is given conditions which perhaps adversely affect the consumption of iron ore in this country, as reflected in lowered steel production and less ore per ton of steel produced. Furthermore, this situation affects the United States' dominating position in the world's production of steel and may be the cause of some European country gaining the lead The practically inexhaustible ore deposits, coupled with vast reserves of excellent coal within easy access, has given to the United States a most favorable strategic place in the running for world domination. However, the disappearance of a frontier, a reduction in the population and a trend towards motor transportation all indicate a falling off in steel demand. If there were any fear of a shortage of ore reserves, the enormous deposits found on the two American continents would be reassuring. Many estimates have been made for the exhaustion of ore resources in the United States. However, none seem to refer to our present situation. These figures apply to the lake ores in particular and to the reserves of the country in general.

In 1927 M. C. Lake credited the Lake Superior district with the very exact figure 1,510,473,621 tons, and predicted exhaustion of this ore in forty years.

A recent newspaper item pertaining to the discovery

of more than 1,000,000,000 tons of ore in Labrador saw fit to assign the short life of twenty-three years to the lake ores.

Olin R. Kuhn credited the United States with 10,477,000,000 tons of actual ore in 1926 and predicted their disappearance in eighty years. This period was extended by him, however, due to 6,000,000,000 tons of foreign ore owned by American consumers. His forecast was predicated on an increase in consumption at a rate of 1,500,000 tons each year. No such increase has occurred, as ore production for the five year period 1921–1926 was at the rate of 60,066,168 tons per year, as against 44,545,563 tons per year for the ten year period 1927–1937. These figures show a loss in production since Kuhn's prediction rather than the progressive gain in consumption he assumed would take place, and which would have called for 166,000,000 tons in 1937 instead of the actual output of 72,106,453 tons. Failure in fulfillment of predictions for the exhaustion of iron ores may be attributed to a better knowledge of reserves, and accounts for the fact that even today our actual tonnages exceed Kuhn's estimate made in 1926.

In the tons of ore per ton of foundry iron and per ton of steel produced, we find another factor affecting the longevity of our ore supply. It is safe to assume that in 1890, 2.10 tons of ore were used in producing one ton of iron commodities which included forge iron as well. The ratio of Bessemer to open hearth steel at 8 to 1 raised the proportion of pig iron required and, incidentally, the ore consumed per ton of final product. The situation in 1912 shows a reduction to 1.47 tons of ore, which was further lowered to .96 tons for the five year period 1933–1937 inclusive. This great reduction in ore required per ton of steel produced reflects the change in the ratio of Bessemer to open hearth—which is now reversed and stands at 1 to 11. This change allows for greatly increased use of scrap, which in some certain non-integrated plants reaches 100 per cent of the charge. The .96 ton figure is further helped on its downward course by increased use of scrap in the blast furnace charge. This increased demand for scrap is met by the ever increasing return of scrap from outside sources and the continued return of scrap originating in the steel mill operation. These conditions predict a still further reduction in the tons of ore per ton of product. Another factor affecting the time when our ores will be exhausted is the question of domestic demand for steel, and if this is less than formerly, the time when our ore supply is depleted will be that much further in the future.

Reliable statistics show that during the period 1913 to 1937 inclusive, the world mined 3,329,998,870 gross tons of iron ore. The United States produced 1,327,529,100 tons of that total, or 39.86 per cent of the world's total. However, for the period 1932 to 1937 inclusive, the rate was only 11.11 per cent. This marked change may be ascribed to a lessened demand due to bad times and due to a material increase in production in Russia, the United Kingdom and Australia. The value of these figures as an omen of the future is not entirely clear. The trend in steel production may clarify the situation. The figures shown below indicate a marked change during 1938 compared with the previous five years.

ANNUAL STEEL PRODUCTION

Country	1933–1937 inc. (Average)	1938
United States	36,343,357	28,000,000
Great Britain	11,096,200	12,000,000
Germany	14,614,124	22,000,000
France	6,612,750	6,000,000
Russia	12,395,655	18,000,000

The trend shown infers a tendency to German domination. There are many elements in German life and activities which go to make her nomination as the successor to the United States in world domination in steel production. Her people are industrious, obedient and studious, and in scientific research they hold an outstanding position. The leadership at this time, is highly aggressive as was that under the old empire, and is based upon national extension which by nature requires new territory, preferably rich in iron ore and other minerals, in an effort to regain much that was lost by the Treaty of Versailles. The recoveries on the eastern border, gained by highly successful diplomacy, may be considered as a return to the geography existing prior to the remapping of Europe by that Treaty.

Germany's strongest bid for supremacy in steel lies in the excellence and extent of her coal measures. This is best attested by reference to Figure 8 showing portions of France and Germany in area only a little larger than the State of Pennsylvania, but holding 86,000,000,000 tons of coal and more than 7,000,000,000 tons of iron ore. The checkered part to the south locates the Minette ore deposits and in Westphalia one hundred and fifty miles distant may be found 25,000,000,000 tons of the best coking coal in Europe. The plebiscite held in 1935 returned the Saar to Germany and automatically gave them 16,000,000,000 tons of coal inferior for coking purposes to that of Westphalia. Germany's interest in the Minette ore must become apparent.

By commercial arrangement Sweden supplies large tonnages of ore to Germany. This ore is received in the Ruhr Basin by a rail and water route which places it at an advantage on unit iron cost over the Minette ore, due to the lower iron content of the latter ore. Development of the Salzgitter fields and the ores obtained through acquisition of territory all add to the possibility of Germany advancing to leadership in steel production without recourse to war. However, war could bring even greater extension.

Mars was the God of War, and iron and war have long since been closely associated. Confirmation of this relation is found in old alchemy and modern pharmacopoeia in that ordinary ferric oxide was known as "crocus martis", and Dud Dudley's book on iron metallurgy, published in 1665, was called "Metallica Martis". In early wars when iron was comparatively rare, the sacking of a defeated town was not considered complete until all traces of this metal had been removed. In more recent years reserves of iron ore have been the

reward to victorious contestants, and these reserves have often been the cause of wars.

The European situation today, in which the Rome-Berlin axis is an outstanding feature, with a place somewhere on the axis for Japan, reflects the relation between iron ore and war—and it is the ambitions of these three nations that forebode a war, and in the order of importance Germany, Italy and Japan are given consideration.

Many authorities believe that the half of the Minette ore remaining with France and overlooked by Germany in the Treaty of 1871, was a contributing cause to the World War. If this is true then it is tenable that these deposits are an even greater menace to peace today than before and it is equally tenable that these ore fields are Germany's ultimate goal. The lessons learned by Germany from the World War were highly instructive, as her loss was due to the breakdown of morale because of the lack of food and necessary war materials. Is it not therefore plausible that her present activities in the Balkans are only preliminary to striking at the main object on their western border? Absorption of the Balkans and the minor states connected with them would bring to Germany added area in excess of 750,000 sq. mi., with a population of nearly 110,000,000. In addition to iron already mentioned, the addition would consist of great agricultural territory and in Rumania rich oil resources would be gained. But the greatest contribution would be an outlet to the Mediterrean via the Black Sea. With the accomplishment of these preliminary steps Germany will then be ready to turn westward in an attempt to regain her position in the country where the Minette deposits are found.

The motivating force in Italy is ambition as well, and is reflected not only in the desire to control the Mediterrean but a desire to increase her power at all times. In Italy's case as well, power means acquiring iron ores and may account for her interest in the Spanish war just won by Franco. The ore to be found in Spain would be a great addition to the mere 20,000,000 tons credited to Italy proper, to say nothing of the possible tonnage in Spanish Morocco, which in amount equals all of Spain's reserves. This interest in Spain also finds the excuse in a nearer control of Gibralter.

Japan is the most powerful nation in the Far East. A dense population finds an outlet in Manchuria and the newly formed Manchukuo. As a result of an undeclared war, Japan obtained definite control of 1,000,000,000 tons of ore. Until that war this ore existed in China but was controlled by the Japanese by commercial arrangements. It is possible to vision that with the final independence of the Philippine Islands, vast ore reserves in those islands will be taken by Japan in an aggressive move. Just how far Japan will go in remaking the map of Asia is unpredictable. However, she should be credited with diligence. Of all the nations of the world, Japan shows far the greater progress in adapting to use inferior grade iron ores.

There is much in the old saying that "It takes two to make a fight", and on this humble saying the possibility of war hinges. Certain European democracies may furnish this second party to the fight, although their motives are clouded by alleged love for their fellow men. It is not possible to entirely divorce from such protestations certain commercial prestiges which would be affected by Germany, Italy or Japan acquiring too much power in the iron and steel trade. Furthermore, for some inexplicable reason these democracies are quite willing to have the United States help them in maintaining the commercial advantages they enjoy.

This paper is not a brief for either side and is offered as an unprejudiced exposition of the world's reserve of iron ore and its significance in peace and war.

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Frequency Relays and MOTOR ACCELERATION *for* STEEL MILL CONTROL

By D. C. WRIGHT, Chief Engineer

Electric Controller & Mfg. Co.

CLEVELAND, OHIO

Presented before the A. I. & S. E Chicago District Section, March 14, 1939.

▲ A FEW months ago, one of our engineers took time out to calculate the amount of current which would flow through various types of circuits, under the assumption that the circuit was connected to a power service of varying voltage and frequency. The results of these calculations are shown by curves in Figure 1, where it will be noted that circuit No. 1 simply included a magnetic relay coil having inductance of 1 h. and resistance of 25 ohms. Circuit No. 2 included this same coil in series with a 10 mfd. condenser. Circuit No. 3 included the same coil in series with a parallel circuit of 10 mfd. capacity and an inductance of 1 h. and 25 ohms.

The amounts of current flowing through these three circuits differ materially at the same applied voltage and frequency. Curve No. 1 is practically flat, after the first build-up at approximately 15 cycles. Curves Nos. 2 and 3 show enormous change at critical points. Circuits Nos. 2 and 3 are so-called resonant circuits, frequently encountered in radio engineering and the points of minimum impedance and maximum current are called points of resonance. These points are caused by the introduction of capacitance in the circuits.

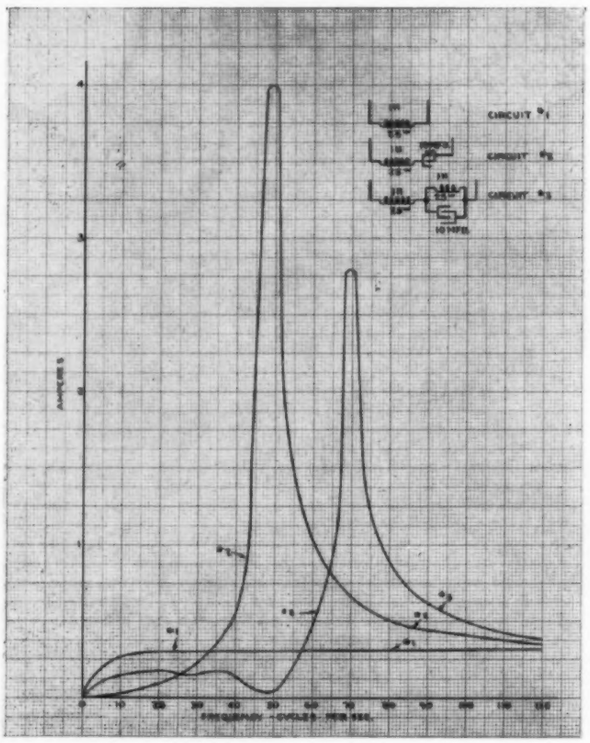
Our engineer was seeking the design of a relay which would give a definite operation, either on pick-up or drop-out, with respect to small change in frequency. He observed immediately that curve No. 1 at frequency above 15 would be of very little use because an enormous change in frequency would be required to get an appreciable change in current. Curve Nos. 2 and 3, however, were extremely interesting, as in certain portions of them very slight change in frequency gave enormous change in current, and therefore, in operating point of a relay.

Further calculations showed that, by changing the capacity of the condenser, the points of resonance, or maximum current, could be shifted to the right or left so as to occur at different frequencies.

Our engineer then went to work to design a relay which would approach these theoretical curves, contemplating that the relay could be subjected to the secondary frequency of a wound rotor motor when being accelerated, and they would thus operate on the changing frequency to properly accelerate the motor.

Figure 2 shows results actually obtained with the new relay connected in Circuit No. 2, where the con-

FIGURE 1—Curves showing results of calculations of current flow through circuits under varying frequency.



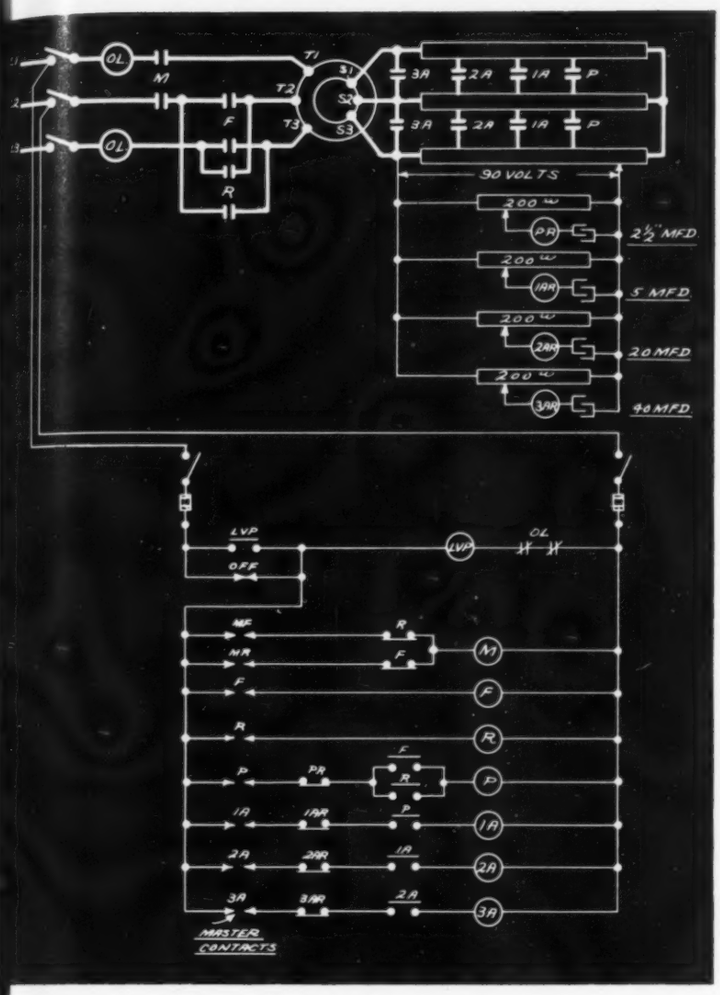


FIGURE 3—Diagram of connections of frequency relay application for accelerating wound rotor motors.

denser in series with the relay varies from 2½ to 40 mfd. It will be noted that the drop-out points for the four values of capacity shown are approximately 63, 44, 22 and 6 cycles, representing minus 5 per cent, plus 27 per cent, plus 61 per cent, plus 90 per cent of speed of a 60 cycle motor while being plugged and accelerated. These curves represent the current flowing through the relay coil with the magnetic circuit closed or with the relay in its operated position.

With a relay of these characteristics available, it was easy to devise proper connections to use them for accelerating wound rotor motors. These connections are shown on Figure 3, where it will be noted that each relay coil, in series with a condenser, is connected across a potentiometer resistor, which in turn is tapped to the secondary starting resistor so as to receive a maximum voltage of 90, on 60 cycle circuits, when the motor primary is first connected to the line. It is a well-known fact that the secondary voltage and frequency vary together and reduce to approximately zero when the motor is up to full speed, thus each relay coil is subjected to a declining voltage and frequency as the motor accelerates from rest.

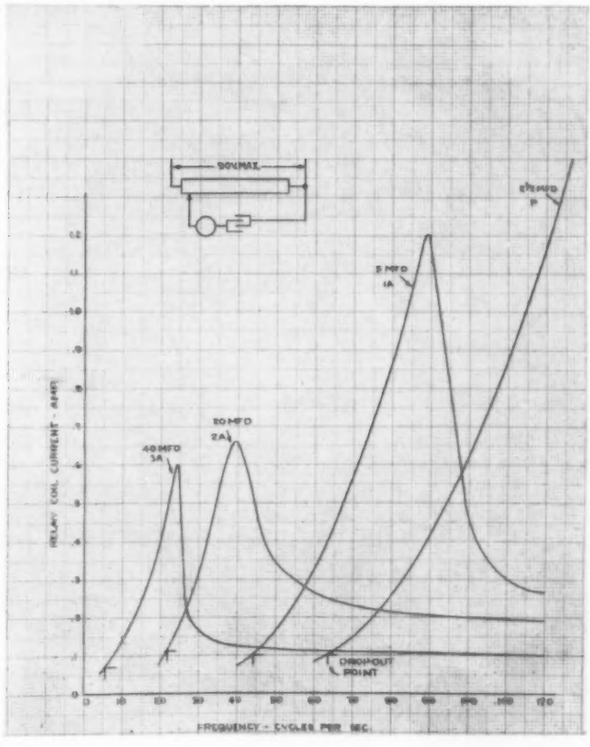
In starting up from rest, with the master thrown to the last accelerating position, all relay coils are subjected to 60 cycles and 90 volts maximum. The relay PR which is the plugging relay and which has only 2½ mfd. in series with its coil, will not pass enough current to operate, and therefore, since this and all of the other relays have normally closed contacts, the plugging contactor will close immediately. However, the remaining relays with greater condenser capacity in the circuit will operate immediately and prevent closure of the accelerating contactors.

As the motor accelerates, voltage and frequency on the relay circuits reduce, allowing each relay to drop open at the operating points shown in Figure 2, thus successively closing the accelerating contactors.

If the master is plugged when the motor is operating in the reverse direction, the frequency applied to the relay circuits is equal to line frequency plus secondary frequency at the moment of reversal, and, in this case, the higher frequency will cause relay PR to operate and prevent closure of the plugging contactor. The motor will slow down and at approximately the moment that it has come to rest, the plugging relays drops open, allowing the plugging contactor to close. Acceleration of the motor in the reverse direction by sequential operation of the remaining relays and accelerating contactors then follows.

A peculiar characteristic occurs in the resonant circuit which allows the relay to drop out at a higher

FIGURE 2—Curves showing results obtained with frequency in circuit No. 2 of Figure 1 with varying capacitance.



current than that at which the relay picks up. This phenomenon is shown in Figure 4 where the open and closed magnetic circuit currents for two relays are plotted against frequency. Referring to the pair of left-hand curves, which would be the current curves for the last accelerating relay, it will be noted that when the motor is first started from rest and 60 cycles is applied to the relay circuit, the current through the coil will be .21 amperes. The relay operates and the current will drop to .11 amperes. This change in current value is characteristic of all alternating current relays in non-resonant circuits, namely, a drop in current as the magnetic circuit closes.

As the motor accelerates, the frequency applied to the circuit decreases and the current at first gradually increases, then quickly reaches a peak at about 25 cycles and rapidly drops, until at 6 cycles and .07 amperes, the relay drops out, closing its contacts to close the last accelerating contactor. It will be noted, however, that upon dropping out at 6 cycles, the current immediately drops from .07 amperes to .046 amperes, thus reducing the magnetic energization of the relay and preventing a fluttering action.

Should the frequency increase on the relay circuit after the relay has dropped out, the current would then increase until at .067 amperes and 7½ cycles the relay would pick up and open its contacts and in doing so the current through the relay coil will immediately increase to approximately .09 amperes. Thus in closing the magnetic circuit, the current through the coil increases instead of decreases, causing the relay to hold in well without fluttering. This peculiar phenomenon of increased current at increased inductance of the magnetic circuit is caused by the shift in point of resonance, which occurs due to the change of inductance of the circuit.

Referring to the pair of right-hand curves; these show the current through the plugging relay, and it will be noted that if 60 cycles is applied to this relay coil, sufficient current will not flow to operate it. However, if 120 cycles is applied, which is the approximate frequency when plugging at full speed, the current is far above the pick-up value so the relay will operate and hold closed until the motor has reduced in speed to approximately 63 cycles when the relay drops out, allowing the plugging contactor to close, which will be at approximately 60 cycles, or zero speed.

If the motor happened to be plugged when running at only 16 per cent speed in the reverse direction the resultant total frequency applied to the coil would be only 70, and the relay will not pick up to prevent closure of the plugging contactor. However, if the speed at the instant of plugging was 25 per cent of full load speed, the resultant frequency applied to the coil would be 75, and since the relay picks up at 73, the relay will operate and prevent closure of the plugging contactor until the motor comes to rest.

Figure 5 is copy of oscillogram showing actual primary current values, time of operation and speeds at closure of the plugging and accelerating contactors, of a reversing plugging controller with frequency control on a 15 hp., 230 volt, 900 rpm. motor driving an inertia load only. The top curves show the characteristics with a minimum time adjusting; the second set shows maximum time adjustment and the third set shows

FIGURE 4—Curves showing open and closed magnetic circuit currents for two relays plotted against frequency.

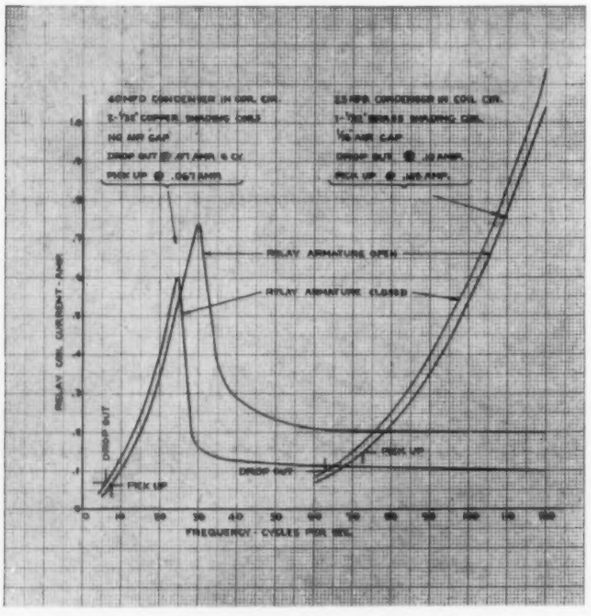
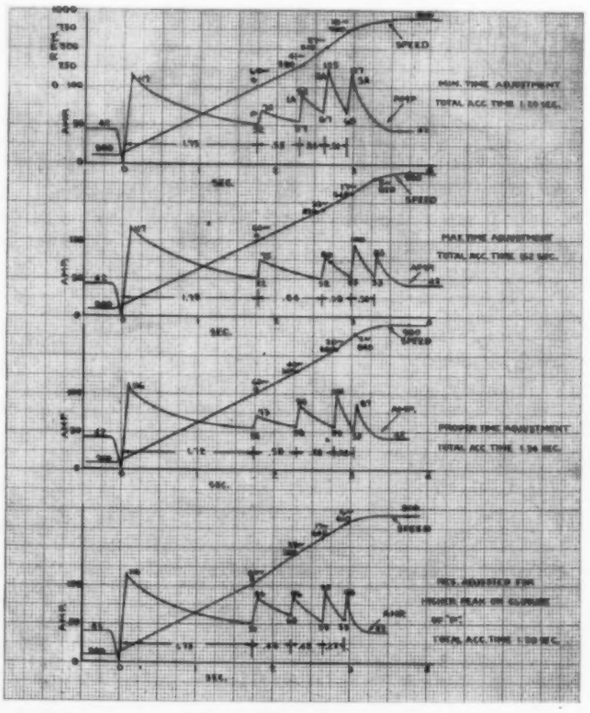


FIGURE 5—Oscillogram showing operating characteristics of control on motor driving only an inertia load.



approximate best adjustment with the resistor taps as available. The lower set shows best time adjustment with a slight change in resistor taps to give smoother acceleration. Such adjustments can often be done in the field to good advantage if study is made of each individual drive.

Figure 6 shows a similar set of oscillograms of the same motor with inertia and full friction load. Comparison of the two sets of curves shows how the frequency relay adapts itself for the load on the motor, thus providing greater time for greater load and preventing excessive current peaks, which would occur if straight time was used for acceleration with the time set to correspond with the operation as shown on Figure 5.

In accelerating a wound rotor motor it is detrimental to cut out the starting resistance too rapidly, that is, before the motor has come up to proper speed because this, instead of increasing the torque, will in many cases reduce the torque. If the load is heavy and the motor will not respond to the change in secondary resistance, the primary current peaks then simply rise until they are sufficient to operate the overload relay. With the same load on the motor, if greater time is allowed for acceleration, the motor gradually increases its speed on each accelerating point and can accelerate the load without excessive peaks. The frequency relay actually matches the acceleration time with the torque available.

It will be noted from the oscillogram curves that considerable adjustment of time was available. For instance, on Figure 6, time of closure of the first accelerating contactor could be adjustable from .99 seconds to 2.7 seconds. This adjustment is accomplished by changing the tap on the potentiometer resistance so as to change the voltage applied to the relay circuit. The range of adjustment of the individual relays by the potentiometer connection is shown in Figure 7, where, by changing the voltage applied to the relay circuit from 90 volts to 45 volts, a change in operating cycles as shown by the curve, can be obtained on the three accelerating relays with different capacity in circuit. The large adjustment for operating point is, of course, obtained by the amount of capacity in circuit, and should additional relays be necessary for acceleration, these would be furnished with different amount of capacity to fit in between the first and last accelerating relays.

I stated in the early part of this paper that the theoretical calculated curve No. 1 showed very little change in current for large changes of frequency above 15. However, it is observed, that for frequencies below 15, a considerable change in current occurs with respect to frequency. This effect is taken advantage of in order to secure proper characteristics of a relay which will hold its contacts closed down to extremely low frequencies.

For accelerating 25 cycle motors, it is necessary to keep the last accelerating contactor from closing, down to frequencies considerably below those proper for 60 cycle motors, such as are shown on the accelerating curves in the preceding paragraphs; and by eliminating

FIGURE 6—Oscillogram from same motor as in Figure 5, but with inertia and full friction load.

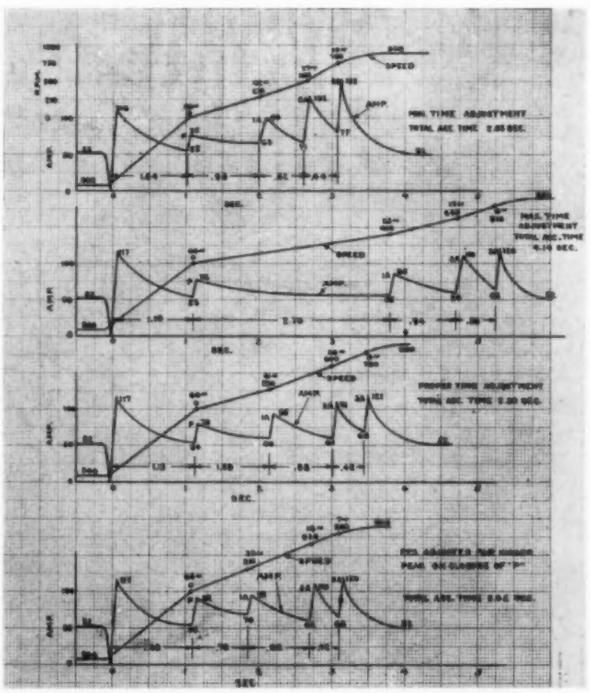
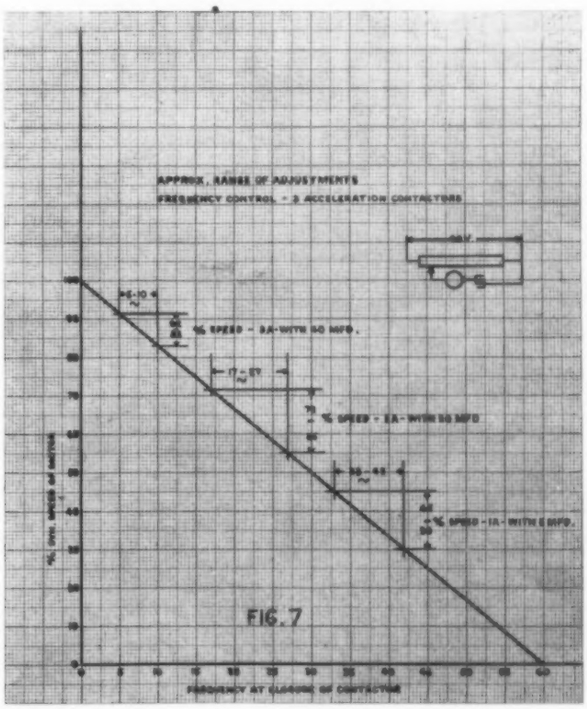


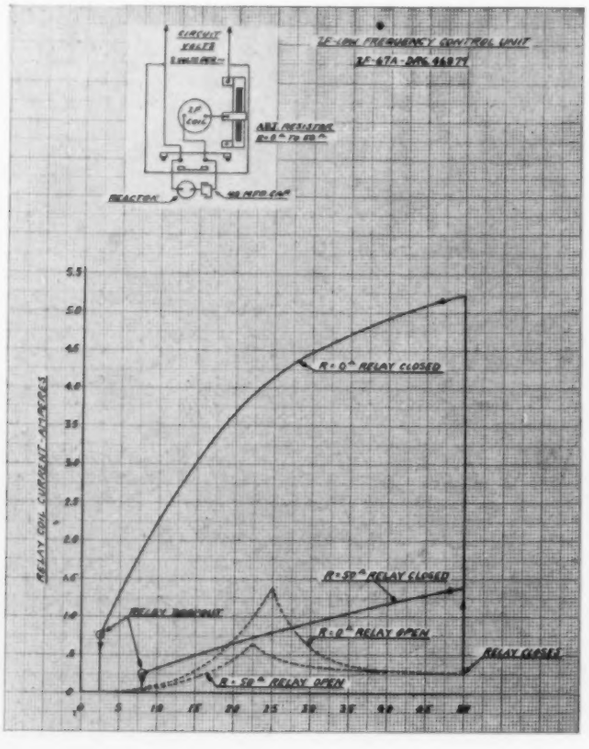
FIGURE 7—Chart showing range of adjustment of the individual relays by potentiometer connection.



the capacity in the holding circuit we are able to get definite hold-in of the relay down to 2½ cycles, as shown in Figure 8, where we take advantage of circuit No. 1. The relay in this case has to be somewhat special because it is necessary to use capacity in the circuit to pick the relay up on high frequency, and then cut the capacity out to hold in on low frequency. It will be noted that the relay is equipped with an extra set of normally-open contacts which short out extra reactance and capacity from the coil circuit when the relay operates. An adjustable resistor is connected in series with the coil to adjust its drop-out value. From the curve, it will be noted that the relay will pick up or operate on any frequency above approximately 15, and in picking up will short out the capacity and extra reactance, causing the current to rise considerably if the resistance in series with the coil is low. As the motor accelerates, the frequency reduces and the current through the relay coil reduces to the drop-out value as shown by the two full line curves. It is possible to adjust the drop-out value to be at any frequency between 2½ and 8 cycles. It will also be noted as soon as the relay drops out, the current through the coil at these low frequencies drops to approximately zero, thus giving a clean break without fluttering.

The series parallel resonance circuit gives very interesting operation, depending upon values of capacity and inductance, and by proper values of these it is possible to design the relay to pick up and drop out on very close regulation or difference in frequency. For instance, with one set of values for inductance and capacity the relay can be made to pick up on 61 cycles and drop out at 60 cycles, or with other values of inductance and capacity the relay will pick up at 92 cycles and drop out at 90 cycles.

FIGURE 8—Circuit diagram and characteristics for low frequency, such as required for 25 cycle applications.



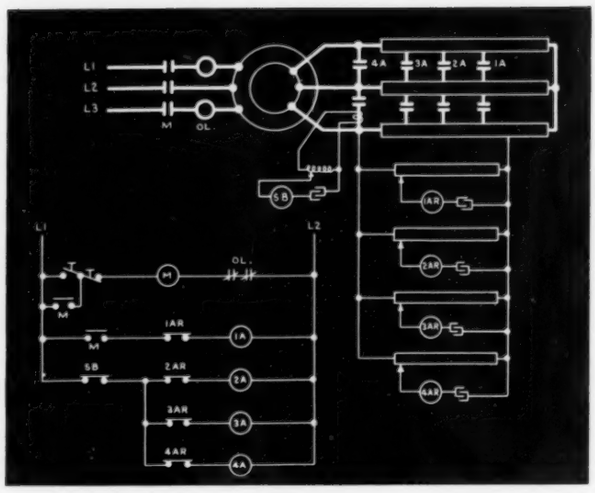


FIGURE 9—Diagram of connections for a drive on a small slabbing mill not equipped with flywheel.

Due to these peculiarities, many interesting applications of the relay are available. For instance, it is possible to use a frequency relay connected in the secondary circuit of the motor when the last accelerating contactor closes so as to insert all, or part, of the starting resistor, should the motor start to slow down due to a suddenly applied load. This will either reduce the torque of the motor, if a large amount of starting resistance is introduced and thus allow the fly wheel to take the load; or if no fly wheel is on the drive, then the operation of the relay can insert a small portion of the starting resistance so as to increase the torque of the motor and give the motor a better chance to pull the overload without actually stalling. Such a connection is shown on Figure 9 which shows a drive for a small slabbing mill not equipped with fly wheel. In this case, should an overload occur the motor will start to slow down, and at about ¾ speed, the step-back relay will insert proper starting resistance to increase the torque above the normal pull-out value, and thus allow the motor to continue to operate without operating the circuit-breaker. When the load is removed, the accelerating relays will automatically reaccelerate the motor to full speed.

There are numerous applications of slip-ring motors where it is desired to stop quickly without using a brake or dynamic braking, and the only other means for stopping is to plug the motor. Figure 10 shows such an application where an additional plug-to-stop relay is shown so as to open the plugging circuit at the instant that the motor has come to rest. By means of the ad-

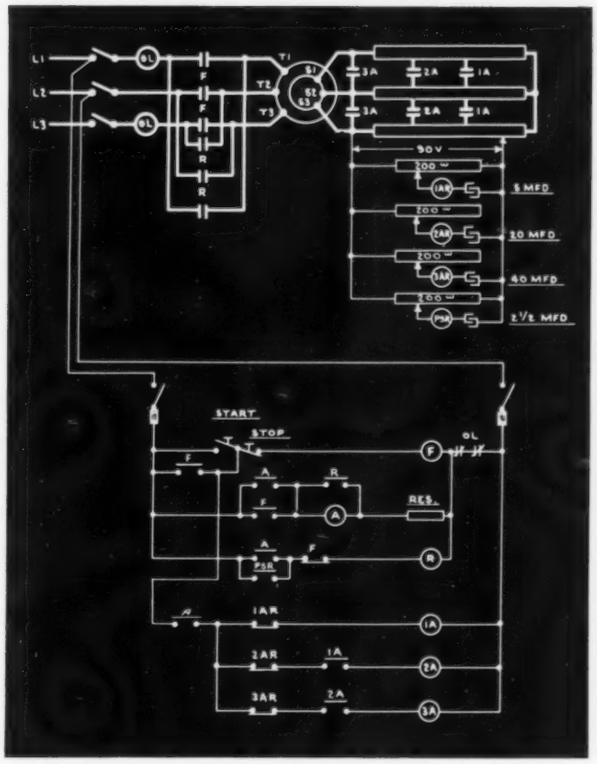


FIGURE 10—Diagram of connections of frequency control on non-reversing, plugging slip-ring motor application.

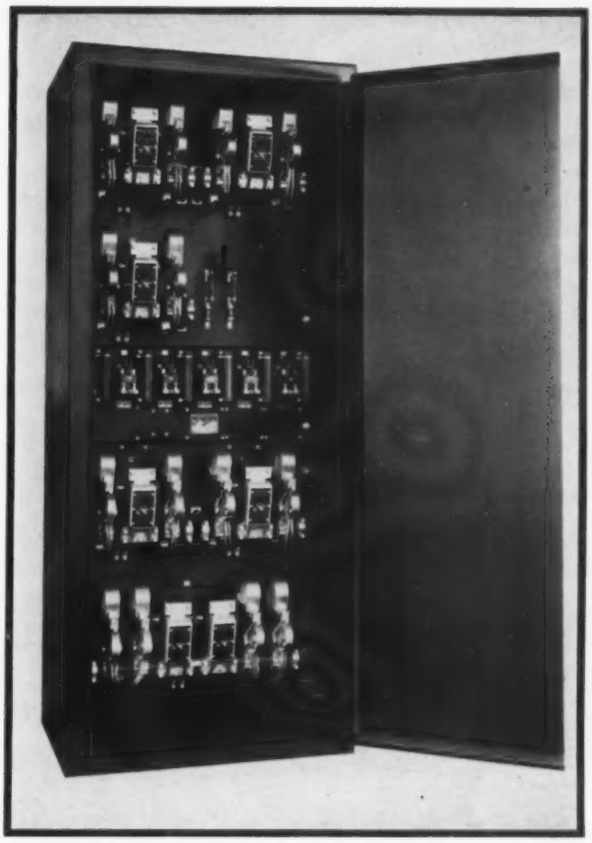


FIGURE 12—View of complete assembled controller for the secondary of a 2200 volt slip-ring motor.

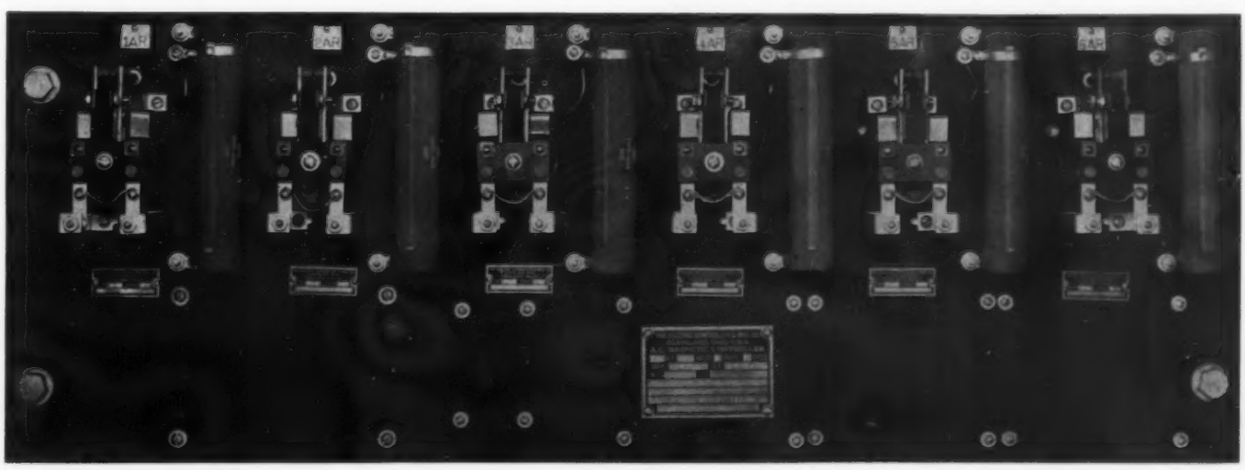
justment on the relay resistor, it is very easy to cause the plug-to-stop relay to open its contact at the instant that the motor has come to rest and before it starts to reverse from the plugging current.

Figure 11 shows the construction of the frequency relays with the adjustable resistor mounted along side of the relay, making it easy to get the adjustment for drop-out value of the relays.

Figure 12 shows a complete assembled controller for the secondary of a 2200 volt slip-ring motor where reversing is done by separate oil-immersed contactors.

We now come to another recent and interesting development in motor accelerating schemes, namely,

FIGURE 11—View showing construction of frequency relays with adjustable resistors mounted beside the relays.



neo-time and neo-time current acceleration secured by neo-timers.

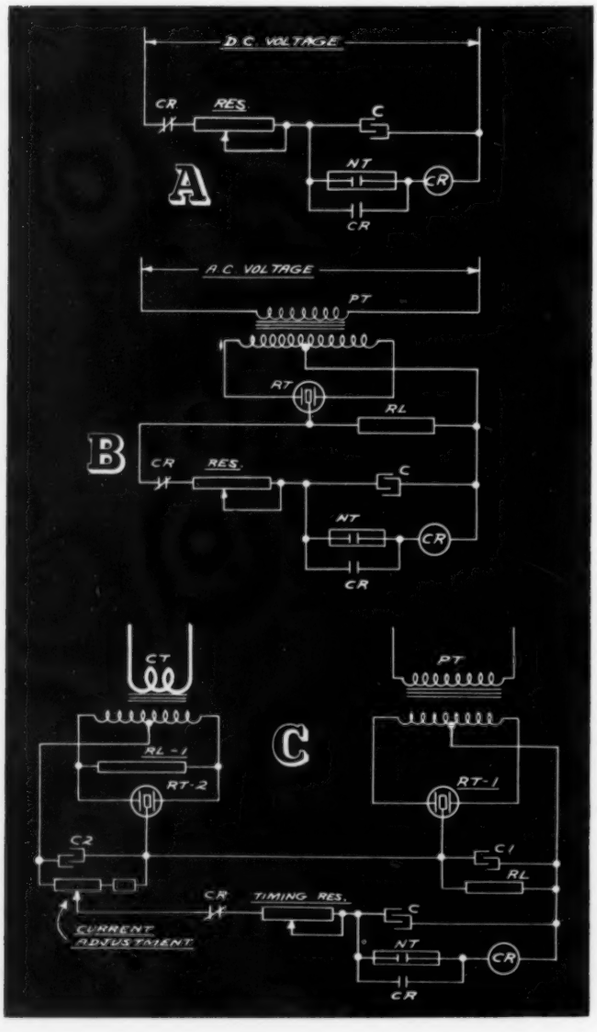
This scheme of timing is not entirely new, as it has been used and proved on weld timers used for several years for timing resistance spot welders. However, it has only been recently that it has been possible to manufacture gaseous discharge tubes of low impedance which would allow sufficient power to flow through them to operate sturdy relays which can be used in most any industry, such as steel mills, where atmospheric conditions are not always of the best. The weld timers as previously used, included a somewhat sensitive relay, which might possibly fail under bad operating conditions; but now that the larger tubes are available, all sensitive apparatus can be abandoned.

The simple elements for the circuit for timing are shown in Figure 13-a where the condenser C is charged by direct current through an adjustable resistor until the voltage on the condenser reaches the ignition voltage of the discharge tube NT, at which instant the condenser discharges through the tube and the coil of relay CR. When this occurs, the flow of current through CR causes it to operate, opening the charging circuit and closing a discharge circuit for the condenser around the neon tube. The time that the relay will remain in its operated position will depend upon the resistance in the discharge circuit and upon the drop-out voltage of the relay. As soon as the voltage from the condenser has reduced to the drop-out voltage of the relay, the relay will then open and re-establish the charging circuit for the condenser and open the discharge path around the tube. Therefore, as long as the direct current circuit is applied to the system the relay will repeat in its operation.

The time to charge the condenser or the time that the relay remains in its open position is directly proportional to the resistance in series with the condenser and to the capacity of the condenser and is inversely proportional to the applied voltage times a constant. With the voltage, resistance and capacity fixed, the time is also proportional to the ignition voltage of the tube.

In order to use this system of timing on an alternating current circuit, it is necessary to have a direct current source to charge the condenser. This is secured by the use of a small radio potential transformer and a rectifier tube as shown in Figure 13-b. The primary of the potential transformer can be made to suit the line voltage, and the secondary is designed to give a safe voltage

FIGURE 13—A. Simple elements for timing circuit.
B. Timing circuit for a-c., using d-c. source to charge condenser.
C. Simplified circuit for time-current timing on a-c. circuit.



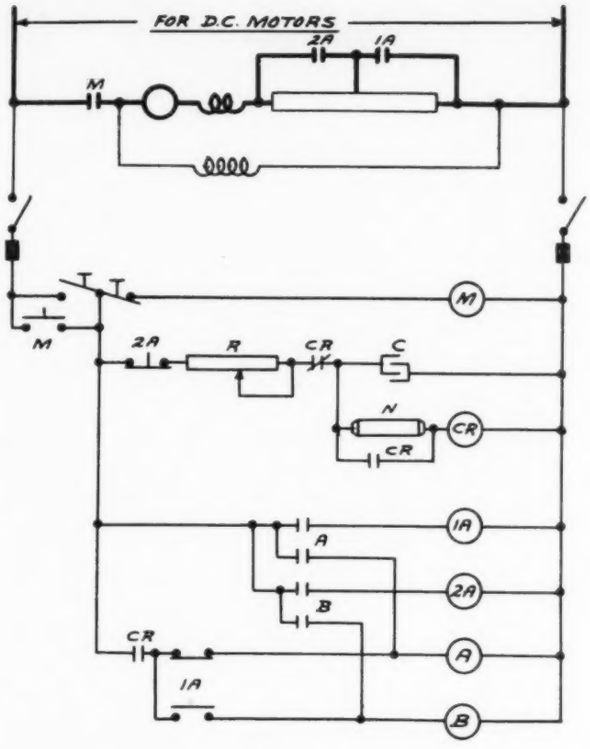


FIGURE 14—Diagram of 230 volt, 3-step time-acceleration starter for d-c. shunt motor.

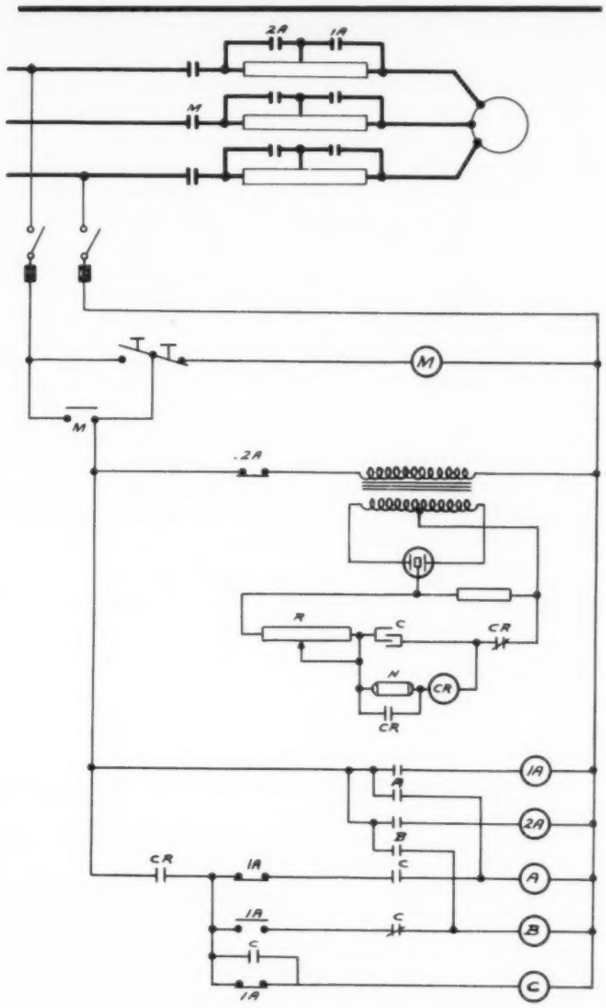


FIGURE 15—Diagram of 3-step time-acceleration resistance type starter for squirrel cage motor.

for the rectifier tube so that the rectifier tube can supply approximately 400 volts for the charging circuit. The rectifier tube is of the cold cathode type, thus eliminating the necessary time for heating the filament of a hot filament tube and eliminating the more or less fragile parts encountered in hot filament tubes.

In all cases, whether used on a-c. or d-c. systems, the ignition voltage of the discharge tube must be somewhat below the lowest applied charging voltage, otherwise, the condenser charge would never reach the potential required to ignite the tube, and cause operation of the control relay. The ignition voltage chosen is approximately 150-160 volts, which is sufficiently below any minimum on a 230 volt circuit to allow proper operation on all minimum dips of voltage.

At the present time, it is impossible to secure low impedance discharge tubes with an ignition voltage about 70 to 80 which will allow enough power to operate a sturdy relay. Therefore, it is impossible to use this scheme of timing on so-called 115 volt direct-current systems.

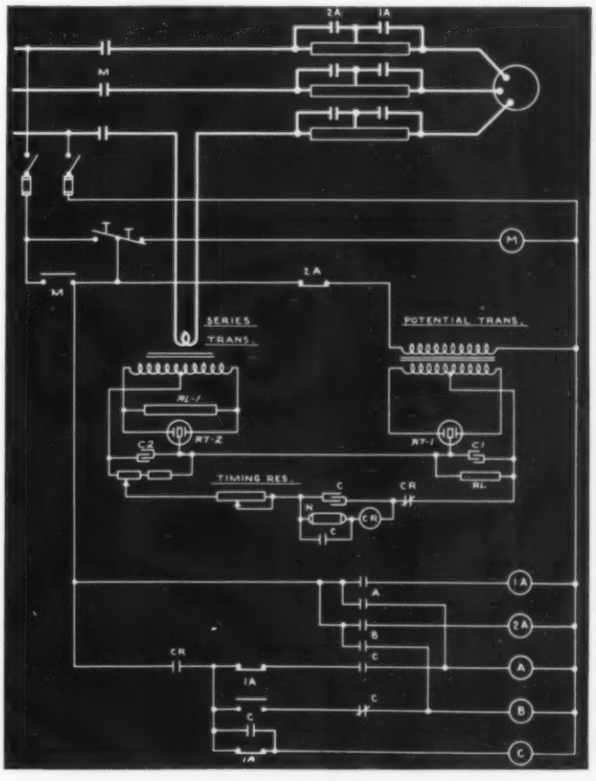
Constant time accelerating systems for motors have certain disadvantages, particularly when accelerating motors driving varying loads. For instance, it is always necessary to adjust the accelerating time to be long enough to prevent excessive peaks when accelerating the heaviest loads, and therefore, when accelerating light loads, the time is much longer than necessary causing waste of time and perhaps causing overheating of certain elements of the motor or control.

Many schemes of time current acceleration have been developed so as to make the time of acceleration depend upon the load on the motor, and this is possible with neo time current timers.

The simplified circuit for time-current timing as used on an a-c. circuit is shown in Figure 13-c where PT is a potential transformer supplying voltage for the rectifier tube RT1, similar in connections to the circuit shown in Figure 13-b. CT is a current transformer, the primary of which can be connected in the primary circuit of the motor or other device, and the secondary supplies voltage to a second rectifier tube RT2.

The connections are so made that the rectified voltage from tube RT2 bucks the rectified voltage from tube RT1 and it is thus seen, that with higher currents in the primary of CT, the combined rectified voltage for charging the condenser will be reduced, and therefore,

FIGURE 16—Diagram showing time-current acceleration for a 3-step starter for squirrel cage motor.



the time for the condenser to become charged will be increased.

It is necessary in these connections to use load resistors RL and RL1, also two filter condensers C1 and C2, which cause the two rectified voltages to remain in phase.

By shifting the current adjustment tap on the resistance supplied with the CT timing element, it is possible to increase or decrease the amount of bucking effect, and therefore increase or decrease the amount of current effect upon the timing.

APPLICATION TO D-C. MOTORS

The application of neo-timers to time acceleration for d-c. motors is shown in Figure 14, where the diagram shows a 230 volt, 3-step starter for a direct current shunt motor. One timer is used to control the closure of the two accelerating contactors 1A and 2A. Therefore, additional relays will be required to switch the timer from one contactor to the other. These relays are A and B and are 2-pole, of similar construction to the CR relay of the timer.

Closure of the push button will close the M or circuit breaker contactor and start current flowing through the condenser and the timing resistance R. When the condenser charge has reached the ignition voltage of the neon tube the relay CR will operate and through the closed type control circuit contact of 1A will close relay A, which holds itself closed, and will also close accelerating contactor 1A.

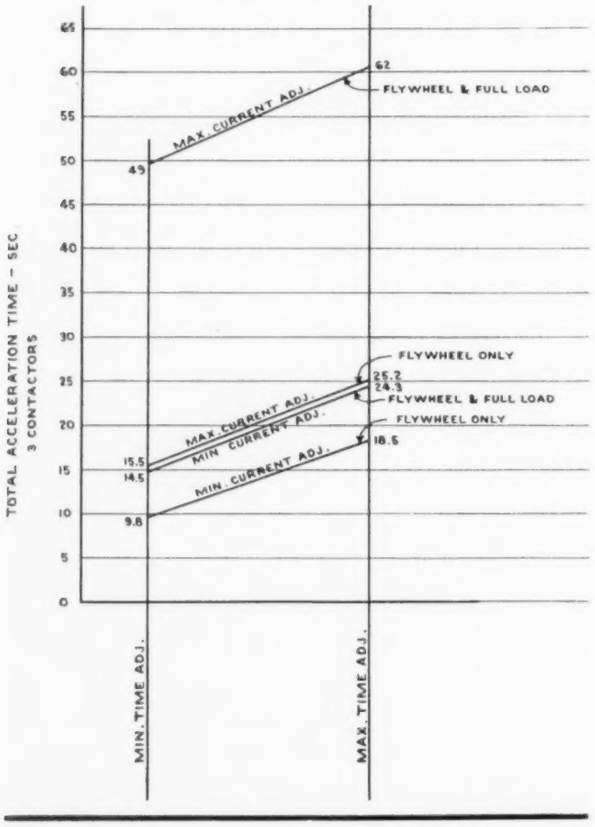
The relay CR remains closed a very brief period of time, only approximately long enough to close relay A. Should it remain closed until after 1A has closed, then it would immediately allow relay B to close which would close contactor 2A. However, as stated before, the relay CR remains closed only about 1/30th to 1/20th of a second, which is a considerable shorter time than that taken for 1A to close, and therefore, on direct current contactors, the scheme as shown operates entirely satisfactorily.

When the CR relay opened, it re-established the charging circuit, and after a time delay operates a second time, when it operates relay B through the open-type control circuit contacts on 1A which had previously closed. Relay B holds itself in and closes contactor 2A completing the acceleration of the motor, and contacts on 2A open the charging circuit to the condenser so that no further action of the timer is obtained as the motor continues to operate.

Pressing the stop button opens all relays and contactors and the circuit is ready for the next acceleration.

In case additional accelerating contactors are necessary, one additional control relay is added for each contactor.

FIGURE 17—Typical range of adjustment for time-current acceleration with 4-point controller on slip ring motor.



APPLICATION TO SQUIRREL CAGE MOTORS

Figure 15 shows application of the neo-timer for time acceleration for a 3-step resistance type starter for a squirrel cage motor. The circuits are similar to those used for the direct current starter with the exception that it is necessary to use two control relays with each accelerating contactor except the last one. This is necessary because of the rapid closure of the a-c. contactors as compared with d-c. contactors. In other words, if only one relay for each accelerating contactor were used, similar to the d-c. scheme, then the accelerating contactor is likely to close before the CR relay drops and thus bring in two contactors at one operation of the timer.

On the a-c. scheme, the first operation of the CR, or timing relay, first closes relay C, which holds itself closed as long as CR is closed, and which when operating, opens the circuit to relay B and closes circuit to relay A, causing A to operate, which in turn holds itself closed and closes the first accelerating contactor 1A.

If the timing relay CR should remain closed, even after 1A operates, it is impossible to close relay B because C is still held in its closed position. Therefore, only one step of acceleration can come in on the operation of CR, and in order to get the succeeding steps of acceleration closed, CR has to drop out which will occur after the condenser has discharged, and when CR drops out the charging circuit to the condenser is again established and relay C drops open.

When the condenser has again become charged, it causes CR to operate for the second time, and this time CR will close relay B through the contacts of 1A and C. B will then hold itself closed and close accelerating contactor 2A, completing acceleration of the motor. Closure of contactor 2A opens the circuit to the timing

transformer and prevents further operation of the timer while the motor is running.

Each additional step of acceleration will require two control relays.

Figure 16 shows time-current acceleration for a 3-step starter for a squirrel-cage motor. The primary of the series transformer of the timer is connected in the primary circuit of the motor so that the load on the motor will be interpreted by the series transformer, and should the load be heavy the charging current for the condenser will be reduced, thus lengthening the time of acceleration.

The operation of the CR relay with respect to the accelerating contactors and auxiliary relays is the same as shown on Figure 15.

A typical range of adjustment for time-current acceleration is shown on Figure 17, which shows the times available on a 4-point controller used for accelerating a 3-phase slip-ring motor. This motor was equipped with a fairly heavy fly-wheel and had means for adjusting the friction load from zero to full load.

It will be remembered that the time-current starter has a timing adjustment which cuts in or cuts out resistence in the condenser charging circuit and also has an adjustment for changing the amount of bucking effect from the series transformer.

The curves on Figure 17 show that, with minimum time adjustment and minimum current adjustment, the total time of acceleration for a fly-wheel load only was 9.8 seconds and with maximum time adjustment the time was increased to 18.5 seconds. When the motor was loaded to full load these times automatically increased from 9.8 seconds to 14.5 seconds and from 18.5 to 24.2. These are not very great increases in time, but it must be remembered that these times are with the minimum available current adjustment. At maximum current adjustment and minimum time adjustment the total time of acceleration was 15.5 seconds with fly-wheel load only and at maximum time adjustment was 25.2 seconds. When the motor was loaded to full load these times increased automatically from 15.5 seconds to 49 seconds and from 25.2 to 62 seconds.

It is thus seen that a considerable increase in time, due to load, can automatically be obtained by proper adjustment of the two adjusting knobs on the timer.

On this particular controller, approximately the maximum time was necessary under the very heavily loaded conditions to keep the line peaks of acceleration in the primary down to 150 per cent full load current. It is thus seen that with straight time acceleration a considerable amount of time would be lost should the long time of acceleration be used for the very light loads, particularly for loads not having fly-wheel effect.

On all of the above accelerating schemes, it will be noted that the same time delay is used for each accelerating contactor. However, in cases where it is desired to change the delay on each contactor, it is very easy to do so by adding additional control circuit contacts and using different timing resistors in circuit with the condenser.

The above timing circuits for acceleration are only a few of many which can be used. For instance, a single timer can be used for accelerating a synchronous motor, using one time delay for securing transition from low voltage to high voltage, and a second time delay for applying the field. Such an accelerator could be either constant time or time-current, in which case the application of the field on a heavily loaded synchronous motor would automatically be delayed so as to being the motor up to its maximum speed before applying the field.

As stated previously, the time delay secured from this condenser charge system is inversely proportional to the charging voltage, and therefore the time delay cannot be extremely accurate if the charging voltage varies considerably. For simple accelerating schemes, slight changes in accelerating time are not of great importance, and therefore can be neglected. However, where extremely accurate time is desired, it is easily possible to use a radio voltage regulator tube and thereby regulate the varying voltage to a very constant amount, and if the voltage is thus regulated, the accuracy of timing will be extremely fine. For instance, using such a regulated timer, tests were made on timers giving 20 minutes delay; and with the operating voltage varying 40 per cent, the time itself varies less than 4 per cent. At constant voltage when charging the condenser for 20 minutes, the maximum variation in operating time was only four seconds.

OTHER APPLICATIONS

Many interesting applications of this timer can be used aside from accelerating purposes as it lends itself to immediate and easy adjustment of time by simply operating the timing rheostat or by changing the condenser capacity by a tap switch.

One interesting application has been to replace the limit switch on furnace top controllers, where the top revolving motor is now made to operate through a certain fixed time rather than through a certain number of revolutions controlled by the limit switch. In this installation, it has been found that the 6 ft. diameter gear at the top of the furnace accurately stops within a minimum variation of 1″ at its outer diameter, or within a variation of 1.6 degrees. The motor driving this furnace top is of the shunt type and therefore runs at a speed depending upon applied voltage, and should the applied voltage vary, the timer itself will be somewhat self-compensating, in that, at lower voltage the motor will run more slowly, but the time given by the timer will be greater. However, there is no compensating means for varying friction, but in several installations of these furnace top control timers there seems to be very little variation in point of stopping of the furnace top.

DISCUSSION

PRESENTED BY

H. W. NEBLETT, Development and New Design Engineer, Inland Steel Company, Indiana Harbor, Indiana.

H. L. WILCOX, Assistant Chief Engineer, Electric Controller and Manufacturing Company, Cleveland, Ohio.

A. J. WHITCOMB, Electrical Engineer, Freyn Engineering Company, Chicago, Illinois.

W. A. PERRY, Superintendent of Electrical and Power Departments, Inland Steel Company, Indiana Harbor, Indiana.

G. E. ADAMS, Electrical Superintendent, Youngstown Sheet and Tube Company, East Chicago, Indiana.

H. R. MIDDLEBROOK, Assistant Division Superintendent of Maintenance, Carnegie-Illinois Steel Corporation, Gary, Indiana.

H. W. NEBLETT: Do you consider these frequency relays as effective on 25-cycle current as they are on 60 cycle, considering that you have fewer cycles to produce an operation in a given period of time? This is asked bearing in mind that you have condensers or other auxiliary equipment to assist the relay operation on very low frequency difference.

H. L. WILCOX: Mr. Neblett asks if I consider this relay as effective on 25 cycles as on 60 cycles. I will confess it gave us some concern, operating on 25 cycles, at first, because we started our development on 60 cycles and everything was clear sailing until we approached the five and six points of acceleration and that carried us into rather low frequencies. Then someone said, "What are you going to do when you come to 25 cycles?", so we got down and did some scratching and as a result we have this second addition to that relay on which we can definitely carry the acceleration down to 2½ cycles. We have no difficulty in adjusting a relay to one cycle variation in drop-out so, as far as I can see, we could easily get eight or ten points of acceleration on a 25 cycle motor.

A. J. WHITCOMB: How close can you set this relay when you go above the rated frequency? For instance, can the frequency on a 60 cycle relay be carried up to 63 or 64 cycles and still have only one cycle variation from the relay setting in the operation of the relay?

H. L. WILCOX: We have no difficulty, by means of the series resonant circuit in making the relay drop out definitely at any frequency from 60 to 120 cycles. The series resonant circuit consists of a one or two microfarad condenser in series with the relay coil, and as you might imagine, the relay coils are not over two inches in diameter. We have no difficulty in having the relay pick up at 65 cycles and above and drop out at 61 cycles or pick up at 95 cycles and above and drop out at 90 cycles. Likewise, I see no reason why it could not be carried up to 200 cycles. If we wish to have the relay pick up to perform a control function on decreasing frequency, we would use a parallel resonant circuit consisting of a small reactor connected in parallel with a condenser and these connected in series with the relay coil.

A. J. WHITCOMB: The application I had in mind was an induction generator, attempting to control the output of the generator.

H. L. WILCOX: I know there is no difficulty, up to 120 cycles, in getting the adjustment precise, to about one cycle.

W. A. PERRY: Have you experimented in using this device to applying field on synchronous motors?

H. L. WILCOX: Yes, but unfortunately we would not be allowed to use it. I think most control engineers are familiar with the Hibbard patent, and there is no use rushing in where angels fear to tread.

W. A. PERRY: Could you tell us which one of these systems you applied to the rotating top of a blast furnace to get away from all the limit switches and other devices?

H. L. WILCOX: I think that credit is due to the engineers of the Bethlehem Steel Company at Bethlehem, Pennsylvania. These engineers were anxious to get rid of all unnecessary apparatus at the furnace top. Many of you, I know, are familiar with the regulations and hazards of gas around a furnace top. When it is absolutely necessary to go up on the top to make adjustments while the furnace is in operation, some companies insist on sending three men: one man to do the job; another man to be ready to pull him out if he keels over; and a third man who stands back where he can see them, and possibly within reach of a telephone. So you can see there is a hazard.

They were anxious to remove all unnecessary apparatus from the furnace top, so they asked us what we could provide in the way of timed travel for the top. They thought the straight time relay would probably do the trick. We all appreciate that a motor will run slower on low voltage, and also slower when it is loaded or when friction is high.

However, a shunt motor does not have much drop in speed with load, providing it is not too heavily loaded, so they said, "We will take a compound motor and use the series field to give us a little extra torque for starting; then the controller cuts out the series field and lets it operate as a shunt motor." The control provides dynamic braking, so they don't require a brake up at the furnace top, and instead of having a limit switch up there to limit the travel, they do it by means of a neo-timer down in the control room. It is so fixed that if the voltage is low on the motor, which would normally cause the motor to run a little slower, the decreased voltage on the timer gives a little more time. I imagine—I say, I imagine, because I did not set it up, myself—that by means of checking

and readjustment one could get it to be practically dead beat. They report that on many check-ups they have been able to stop within one inch on the six-foot diameter ring that goes around the top.

I am unable to say why we need such accuracy. When that skip goes up and dumps a large charge of coke into the hopper (and we all know the angle of repose for different materials depends on the coarseness and wetness), I can't see why plus or minus five degrees in dumping that stuff into the furnace would be objectionable. I do know that certain blast furnace superintendents have had men up there for a day at a time to see how accurately the thing stops. I respect their opinions. There may be some reason for it. If there is anybody here tonight who could enlighten us on the necessity of such fine adjustment on the stopping of the furnace top, I am sure all of us would be interested in knowing of such reasons.

However, you can see the advantage of taking the limit switches and everything away from the top of a furnace. Against those advantages there may be the disadvantage of not being able to stop on the line.

In this application we simply had a circuit as shown in Figure 00. The voltage was taken from the same source that fed the motor. If the voltage was low we automatically got a little more time. When circuits were set up for starting the top rotating, a control circuit also energized this timing circuit. When this worked, a normally closed contact on relay CR dropped out the "M" contactor and stopped the top rotation.

A. J. WHITCOMB: I was interested in your discussion of the distributor on the top of the furnace. The reason for the desire for accurate setting or stopping of the top is due to the fact that the coarse materials are thrown to the far side when the material is thrown into the hopper on top of the small bell and the "fines" drop on the near side. Also, the left skip car on a two car skip hoist throws its material to the left side of the hopper while the right car throws its material to the right side of the hopper. They want to rotate the top to deposit the coarse and fine material equally all the way around the furnace. The only way to do that is to keep equal angular rotation. Probably three or four degrees does not make so much difference, but the big thing is, how accurately can you control this timing when you get wide variation in voltage? A modern blast furnace has fairly uniform voltage but there are many old blast furnaces running in the country today where the ore bridge and the unloaders or the car dumper or the skip hoists all come in at different times, with the result that you get voltage drops that run 275 volts down to possibly 210 volts. I am wondering what happens when you get such extreme voltage fluctuation on your shunt motor, with the timing?

H. L. WILCOX: I think I can answer that. There is no difficulty in arranging the time by trial and by adjustment so that the variations of travel, as a result of varying voltages, can be practically ironed out. I mean that if we have a 10 per cent drop in voltage the motor will run slower and we can give sufficiently more time automatically to correct that. I am confident that we can go practically as far as you wish. I have seen 230 volt systems operating as high as 275 volts, which obviously is abnormal, and then going down below 200. That is not the big problem. The big problem would be to have constant voltage but varying load. Some fellow on the maintenance gang would fail to grease the top or maybe they'd send up more than the average load of ore—that, in my opinion, would create more disturbance than variations in voltage for which I am sure we would be able to compensate. I can only report the findings on the Bethlehem installation regarding accuracy and satisfactory performance.

A. J. WHITCOMB: I also might ask you about the neo-time relay when used on d-c. power. You told us you could get up to twenty minutes, and I presume you can cut that down to just a few seconds, but on any given relay what is the percentage of adjustment that can be made, above and below the normal setting, by the customer or the user of the relay?

H. L. WILCOX: I don't believe we would make one combination that would give you from a quarter of a second to twenty minutes, but with one given capacitor, and one clarostat, which is a small rheostat, we would get as much as a fifty-to-one change. That does not sound like much, but if we want greater changes than that, we provide a ten-point selector switch, which is just like a little radio switch, and each point will cut in a wire-wound resistor, smaller than your little finger, having maybe 100,000 ohms in each resistor. Each step of the ten-point selector switch will then be graduated by the clarostat, and we can get, maybe, from 2 cycles up to two seconds on the first step and from two seconds to four seconds on the second step and from four to six seconds on the third, and so on. Longer time requires larger capacitors and higher resistance. It would not be practical to make something that would go from half a second to twenty minutes on one step.

G. E. ADAMS: I would like to ask Mr. Wilcox if this frequency relay has been used for synchronizing work in control. For example, in case we desire to connect two drives together mechanically by engaging a clutch when they are both running at the same speed, it appears that a frequency relay could readily be used to determine when the clutch should be engaged and also to set up the circuit for closing the clutch. I am thinking of synchronizing a pouring reel with the finishing stand of a rod mill and many other similar control problems. Instead of using d-c. tachometers and voltage balance relays, which are not entirely satisfactory, why couldn't we use a differential selsyn driving a small pilot a-c. generator to which one of these frequency relays would be connected, and thereby obtain a more accurate and dependable means of operating the clutch?

H. L. WILCOX: The frequency relay, bear in mind, has not been on the market a long time, so there is nothing in the field using these relays for synchronizing. However, as an illustration of what might be done by means of these frequency relays, I might advise that I used one for the purpose of synchronizing

two slip-ring motors, using the tie motor or selsyn motor principle.

You all appreciate the precision that is necessary to make two motors pull into step with the tie motor principle, especially when these are operating as three-phase motors. The tie motor principle is not well enough known but that I might give a word in explanation. If you have two identical slip-ring motors connected with their primaries in parallel and their secondaries opposing each other, then if you drive one motor by an outside means the second motor will follow that motion identically. But if they are pulled out of step just the amount of one pole, they are immediately thrown out of phase and are unstable, and one motor will run away. It will come up to synchronous speed independent of the other when such a condition exists.

I endeavored to re-unite them, or re-synchronize them, and I did it with the frequency relay by measuring the frequency of one as opposed to the other, and the results were extremely successful. I don't propose that this is an application that is available for the trade, but it does illustrate the precision and the possibilities of the frequency relays. There is no difficulty at all in having a relay operate at precisely the same frequency every time and where that can be used, it will do its part.

H. R. MIDDLEBROOK: Will you discuss the effect which variations in line frequency will have on the operation of the frequency controlled starter?

H. L. WILCOX: There is no doubt that variations in line frequency would affect the actual speed of a slip-ring motor when the particular frequency relay operated. Obviously, if you had a relay set to operate at 40 cycles, it would operate at 40 cycles, independent of the line frequency. But the motor would be running a little faster at 40 cycles in the secondary if the line frequency was down. Let's assume that line frequency was abnormal and dropped from 60 to 50 cycles—then, 40 cycles represents a higher percentage of synchronous speed than it does when the line frequency is normal or high, so, while the frequency relay would operate at exactly the same frequency every time, it might represent a difference in per cent of the motor speed. We appreciate, however, that line frequency does not vary more than a half or one cycle, and so I would say the effect is negligible.

RHEA and LEDING Discussion

CONTINUED FROM PAGE 41

their cost by about 25 per cent, more or less. We should also remember that the cost of the main drives for a cold strip mill is not much more than 20 per cent of the total investment, considering the mills, buildings, auxiliary equipment, etc. Therefore, a 25 per cent increase in the cost of the main drives means only 5 per cent increase in the total investment, and the rolling tonnage will go up, according to Mr. Schnure, 10 per cent. This means that the extra investment will pay good dividends.

As a matter of fact, some of Mr. Schnure's assumptions should be slightly corrected. If the mill speed is increased by 33 per cent, the rolled tonnage can be easily increased by 15 per cent, instead of 10 per cent. The capacity of the main drives does not have to be increased 40 per cent, because an increase of 30 or 35 per cent will be ample. If these facts are taken into account, then the advantage of speeding up the proposed mill becomes still more evident. Furthermore, the labor and maintenance costs on, say, two 2000 feet per minute mills are obviously less than those on three lower speed mills delivering strip at 1200 feet per minute or thereabouts.

The above reasoning is well justified by the evident trend toward higher and higher rolling speeds in tin plate production. Five-stand mills operating successfully at 1750 feet per minute are in existence. Still higher speeds are contemplated and are within sight.

The remarks of Mr. Kenyon about the advantages of a booster for assisting the reel motor to accelerate in step with the mill are well taken. It might be well to correct, as a matter of record, his reference to 1934 as the date when such boosters were first employed. As a matter of fact, we applied in 1931 such a booster to a tension reel at the end of a 4-stand high speed cold strip mill. Broadly speaking, such boosters could also be applied, and with good results, for the main drive motors, assisting materially in the problem of tension control between the stands, particularly at the low speeds. In fact, we considered such an arrangement in the last year and believe the only objection to it is, of course, the high first cost, especially in view of the fact that satisfactory results are being obtained by other means.

The authors, with Mr. Neblett, hope that this paper will further stimulate interest among operators in the important problem of studying the effect of speed and tension on strip gauge in order to reduce to a minimum the scrap obtained during acceleration and deceleration.

REPUBLIC EXPANDS SOUTHERN PLANT

To meet a greatly increased demand for steel products in the South, Republic Steel Corporation has substantially increased the range of products produced at its Gulfsteel Division in Gadsden, Alabama. Construction of a 408 x 72 ft. building, together with a bar yard 360 x 72 ft. in size, has been completed for the installation of a wire mesh department.

Wire mesh is extensively utilized as reinforcement for roads and in building construction. It is made of wire or rods up to 5/16 inches in diameter on welding machines. The company has installed two enormous automatic welding machines for this purpose which together with the reels which feed the wire to the machines and the coilers and shears on the delivery end are some 225 ft. in length. Automatic machines for producing electric welded mesh of this type were developed and first used successfully by the Truscon Steel Company, a Republic subsidiary.

In connection with extensive repairs and overhaul of the company's plate making mill in Gadsden wider rolls have been installed which permits the production of plates of an increased width. The product of this mill is used extensively in shipbuilding, railroad car construction, tank making, and other industries. Approximately fifty nut and bolt machines have been installed, giving the company a complete department for the manufacture of this product.

The hot bolt and nut department was installed at the end of the bar mill and has necessitated an extension to the existing building. The cold bolt department was installed at the end of the wire mill. With present capacity the company will produce a normal range of nuts and bolts consisting of several hundred kinds and sizes.

Equipment has also been installed for the manufacture of a specially designed patent roofing. The machine will have a capacity of several hundred tons a month. To meet the demand for steel shingles in the South, machinery has been added for this purpose. Complete bar bending and shearing equipment together with a warehouse also has been installed.

ROLLED PLATE FOR FLYWHEELS

▲ In recent years, machine designers in increasing numbers have specified the use of rolled steel plates for flywheels. Steel plate flywheels can be operated safely at much higher peripheral speeds. One steel flywheel now in service is reported to be used at peripheral speeds up to 14,000 feet per minute. In addition, the use of steel plate permits the designer to effect appreciable savings in flywheel weight, while eliminating pattern expense. One large machinery manufacturer prefers steel plate flywheels because they are easily designed, simplify flywheel manufacture, and give a neat appearance to the equipment on which they are used.

Lukens Steel Company, Coatesville, Pennsylvania, recently produced two steel plate flywheels, the largest and heaviest in gauge and weight ever made in steel plate. These were made for the Mesta Machine Company of Pittsburgh, Pennsylvania. Each of these flame-cut steel plates, before machining, weighed 56,315 pounds, and measured 165¼ inches in diameter and 9⅛ inches in thickness. They were used in the fabrication of flywheels for drives of a new hot wide strip mill in the Pittsburgh territory.

Production of these flame-cut steel plates required pouring of the two largest and heaviest ingots ever cast at Lukens, one ingot being made for each flywheel. The ingots were 135 inches high (including the 27 inch

View showing the rolling of large plate as used in the fabrication of flywheels.

high hot tops), 90 inches wide and 40 inches thick. Each ingot weighed 110,000 pounds, including the 17,000 pound hot top. Each ingot was rolled on the 206 inch mill (which can produce plates up to 26 inches in thickness) into a plate 200 inches long, 170 inches wide and 9⅛ inches thick, weighing 87,090 pounds.

From each of these rolled plates, a circular plate was flame-cut measuring 165¼ inches in outside diameter, 9⅛ inches thick, with a shaft hole 29 inches in diameter in the center. Each flame-cut plate weighed 56,315 pounds, and they are the heaviest steel plates ever produced.

After flame-cutting, the circular plates were transferred to the machine shops and there smooth-machined on the inside diameter to a tolerance of plus 0, minus .005 inches, to shaft hole size of 31.015 inches. Other surfaces were rough machined to finished flywheel size of 164¼ inches in outside diameter and 8 3/16 inches in thickness, weighing 49,850 pounds.

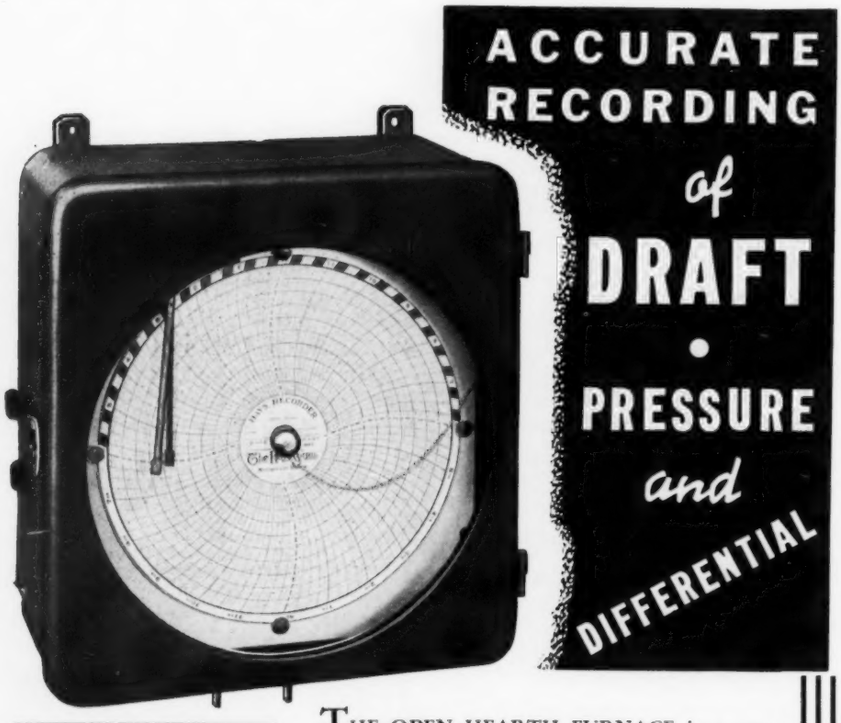
HANGERS FOR FLOODLIGHTS

▲ Equipment for disconnecting and lowering high positioned lighting fixtures for cleaning or relamping, has been in use for years, but its application to floodlighting units has been very limited. Floodlights need servicing just as much as other lighting equipment, but no means had been devised to "point" the light beam in the desired direction or to make certain it would return to the same position after disconnecting and lowering.

These obstacles have been overcome by engineers of the Thompson Electric Company. This company has developed means to provide a complete range of radial adjustment and to lock the floodlight so that when it is returned after lowering, it will always position itself exactly.

To enable quick ordering and easy installation a unit package has been assembled. This package contains the hanger, U-bolts for mounting to the bracket, a bracket end and slip-fit elbow to enclose the electrical conductors, a fully enclosed corner pulley with a flare end, 25 feet of galvanized

Equipment for disconnecting and lowering high-positioned lighting fixtures.



Two draft values, two pressure values, two differential values, or a combination of any two of these three values may be recorded. Hays Draft Recorders are sensitive enough to register accurately increments of .0025 inches water yet are built husky enough to withstand the jars and dirt of steel mill operations.

THE OPEN HEARTH FURNACE is a very leaky structure at best. Therefore, draft conditions within the furnace are apt to be variable. The only way to prevent large leakage of gases is to maintain balanced draft conditions in the hearth.

The *Hays Series OT Supersensitive Draft Recorders* keep an accurate record of draft, pressure or differential—knowledge very essential to effective furnace operation. By connecting the instrument with the risers from the checker chambers to the furnace at a point just above the level of the charging floor a permanent record is made of pressures and drafts at these points. Balanced conditions on each end can be readily obtained and the amount of this draft is an indication of the draft on the bath.

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MICHIGAN CITY, INDIANA, U.S.A

chain and galvanized lock box, and a spring to keep the chain taut and prevent wind slap.

Now that floodlights can be cleaned and serviced without the hazard and inconvenience of climbing up to them it is believed that there will be a much wider use of floodlights for industrial purposes.

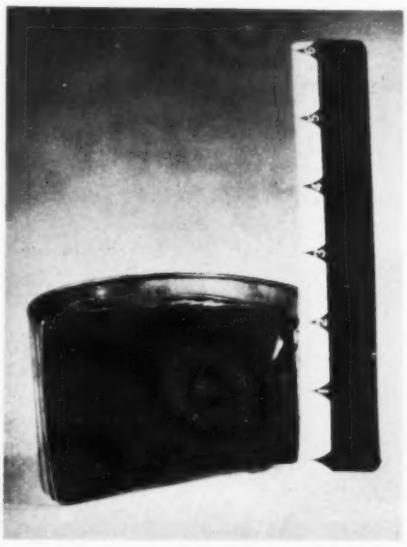
NEW VARNISH FOR INSULATION

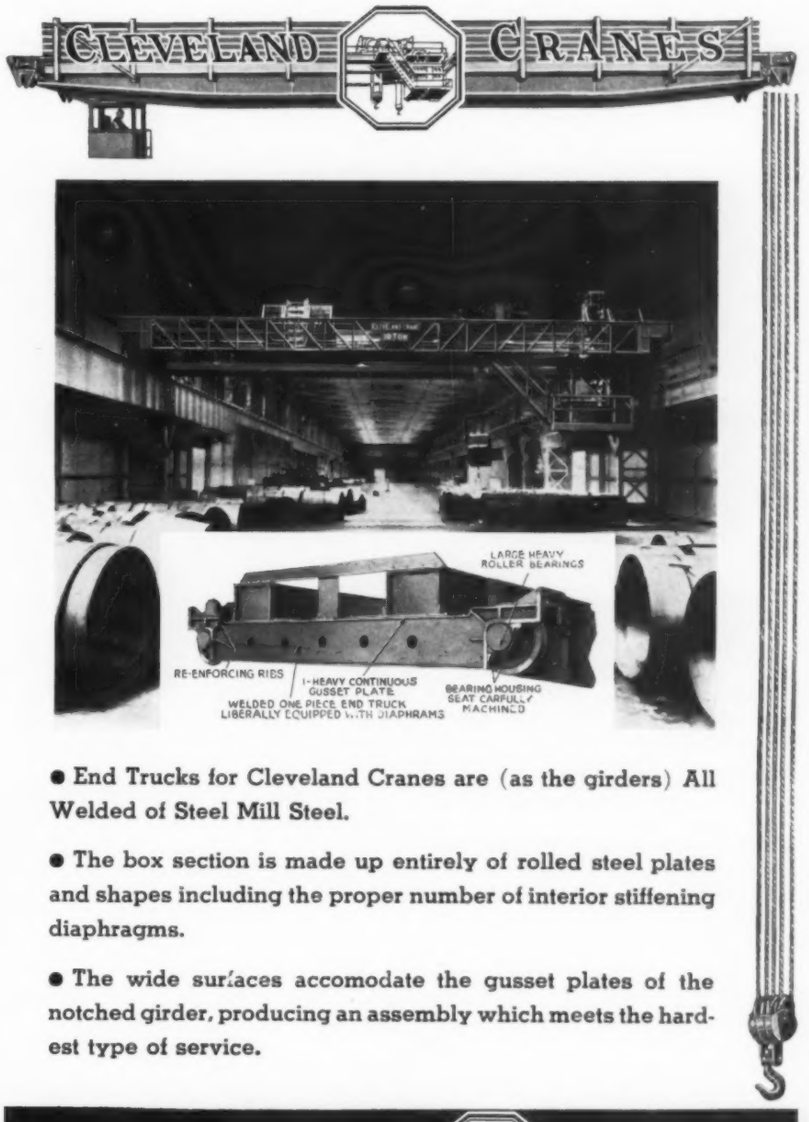
Development of a radically new type of insulating varnish for use on electrical windings has been announced by the John C. Dolph Company. This new grade of varnish, known as Synthite PG-1 clear baking varnish, possesses the ability to dry throughout even the very deepest windings. In the past there has always been a danger of an insulating varnish sealing and trapping wet varnish in the interstices of the windings. While this may have been partially overcome with some modern varnishes at the expense of flexibility, it is believed that this new product is the first to guarantee curing throughout, and at the same time offer an appreciable degree of flexibility.

In order to demonstrate the ability of this varnish to dry throughout, a quantity of the varnish was placed in an ordinary one pound can. This was then baked in an oven at 250 degrees F. As the varnish shrank it was refilled so that a depth of two inches was maintained. The cup of varnish was then baked for a long period to insure thorough curing throughout. Finally the can was cut in half and the varnish was found to be one solid mass. There were no wet spots nor any trapped solvents. Such a laboratory test would probably never be duplicated in actual practice. It is difficult to imagine a coil that would have voids as deep as two inches, but coils treated with this varnish should definitely dry throughout.

Another outstanding feature of this new varnish is its high dielectric

View of test can of varnish, showing thorough curing throughout.




CLEVELAND CRANES
LARGE HEAVY ROLLER BEARINGS
RE-ENFORCING RIBS
I-HEAVY CONTINUOUS GUSSET PLATE
WELDED ONE PIECE END TRUCK LIBERALLY EQUIPPED WITH DIAPHRAMS
BEARING HOUSING SEAT CARFULLY MACHINED

● End Trucks for Cleveland Cranes are (as the girders) All Welded of Steel Mill Steel.

● The box section is made up entirely of rolled steel plates and shapes including the proper number of interior stiffening diaphragms.

● The wide surfaces accomodate the gusset plates of the notched girder, producing an assembly which meets the hardest type of service.

ALSO BUILDERS OF CLEVELAND TRAMRAIL MATERIALS HANDLING EQUIPMENT

CLEVELAND CRANES

THE CLEVELAND CRANE & ENGINEERING CO.

1131 Depot St.
WICKLIFFE, OHIO.

NEW YORK DETROIT PITTSBURGH CHICAGO

value. As a result of tests run in accordance with the procedure outlined by the American Society for Testing Materials, this was found to be in excess of 1800 volts per mil. Other qualities are excellent acid and alkali resisting properties.

Additional information or samples for test purposes are available to readers of the IRON AND STEEL ENGINEER.

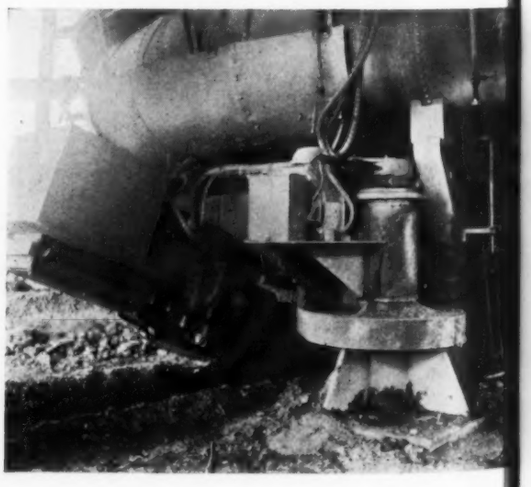
NEW TYPE MUD GUN

▲ To meet the demand of blast furnace operators for a clay gun that will be altogether independent of the furnace structure, Edgar E. Brosius, Inc., Sharpsburg, Pennsylvania, has developed the pedestal type. This gun, with its crane, is mounted on a pedestal which is secured to a foundation (separate from that of the furnace) erected at the side of the iron trough. The gun is swung to and away from the tapping hole by means of a motor placed on a bracket at the top of the pedestal. This motor transmits its power through a worm and spur gear reducer to a pinion which is meshed to a stationary gear attached to the pedestal; the drive is positive and the gun is turned at a constant speed.

By means of a lever fitted with a roller which travels on an inclined plane, the gun is tilted at a predetermined point and at the proper angle to hit the tap hole in exactly the correct position. No clamping mechanism is required as the motor operating through a system of gears, locking worm and magnetic brake holds the gun securely to the tap hole.

The gun proper is of the same design as that now in service on 75 blast furnaces in the United States and abroad. The clay piston, whose rod is a double rack, is driven by an individual motor through a worm and spur gear reduction. The barrel has a capacity of 9 cubic feet, equivalent to almost five wheel barrows, which is ample clay to stop any tapping hole. This new pedestal type gun is now in operation and is giving excellent service. The cast steel crane is so tapered that the operator has a clear view of his tapping hole at all times and can pass under the boom to do any work around the trough while the gun is in the hole; this is a very important feature. It is also especially valuable in case of a breakout (which, as every operator knows, does happen occasionally) as there is nothing near the floor to be damaged.

This new type clay gun is altogether independent of the furnace structure.



MORE LIGHT FROM FLOODLIGHTS *WITH THE* NEW THOMPSON HANGER

Thompson engineers have done it! Two new developments, exclusively Thompson's, now make it possible to apply disconnecting and lowering hangers to floodlights just as successfully as to reflector lighting fixtures. With Thompson Hangers, floodlights now may be installed without regard for the servicing problem, and maximum lighting efficiencies may be maintained, safely and economically. And Thompson Hangers make it possible to mount as many as 13 units on one pole.

Radial Adjustment Adapter

This ingenious device permits radial adjustment of the floodlight beam to within limits of less than 3 degrees. And adjustment can be made from the ground, Economically, Safely.

Lock-Beam Stem

After the floodlight is properly positioned, the lock-beam stem secures it there. No matter how many times the unit is lowered for cleaning. relamping, etc., it will always return to its exact original position.

The new # 177 Hanger in a typical floodlight application. Note how chain and wiring entrances are weatherproofed.

T·E

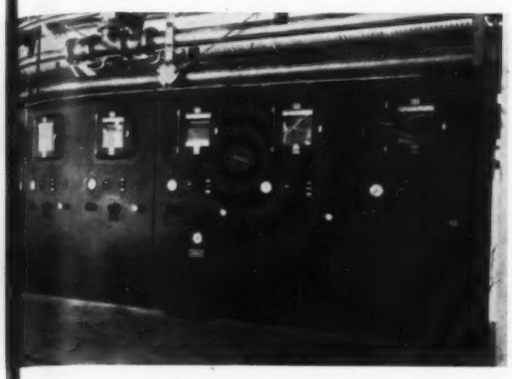
If you haven't the new Thompson catalogue. ask your electrical distributor for one. Or, write The Thompson Electric Co. 40 pages showing new equipment, new uses, new protection, and new economies.

THE THOMPSON ELECTRIC CO.

1101 POWER AVE., N. E. CLEVELAND, OHIO

CONTROLS IMPROVE STEEL QUALITY

▲ Today's exacting demands for high quality steel have raised the standards, which steel products must meet, to a higher level than ever existed before. For example, the use of deep streamlined fenders and hoods has



made it necessary that any steel used for this purpose possess exceptional qualities, especially with respect to uniformity of surface finish and grain structure.

The use of automatic combustion controls has been one of the important factors making possible this higher quality steel. Actual operating results with furnaces under automatic control indicate that the same factors which make for quality also make for lowest heating cost. For instance, the installation of five new circular soaking pits, with complete control, at Atlanta Steel Company, Atlanta, Georgia, has resulted in superior heating and reduced fuel costs as compared with older pits which they replaced.

These new pits are natural gas fired. A gas pressure regulator maintains constant gas pressure to all pits, and gas-air ratio regulators maintain proper fuel-air ratio to each of the five pits. The panels, gas pressure, and fuel-air ratio controls were designed and engineered by the Hagan Corporation.

NEW GALVANIZERS START PRODUCTION

Wheeling Steel Corporation recently started production on its four new sheet galvanizing units located at the Steubenville, Ohio, plant. One pot is now in operation and the remainder is to follow in the near future. Rated capacity of the new equipment approximates 6,000 tons monthly.

FLUORESCENT LAMP AUXILIARIES

To meet the exacting demands of the new type fluorescent high efficiency lamps, the Jefferson Electric Company of Bellwood, Illinois, has added a line of auxiliaries. Incorporated in these auxiliaries is the experience gained through the many years of manufacture of transformers for luminous (Neon) tubing, street lamps, sun lamps, mercury lamps, and the like. The new auxiliaries, are compact and small for easy, concealed installation in strips, channels and lamp fixtures. The coils inside the metal case are machine wound and treated to remove and prevent absorption of moisture. The entire unit is sealed in all-weather resisting compound. Sizes are made for various fluorescent lamp capacities.

Fire! *demands prompt action*

When fire alarms sound in a large eastern metropolis, tall buildings may be endangered. Prompt action must be taken. High pressure pumps must operate instantly. The 6000 volt 800 HP motor pictured above is one of five used to deliver water at 400 lbs. pressure for this service. We are proud of the fact that since it was reinsulated with DOLPH'S CHINALAK Black Baking Varnish, it has given no trouble at all.

In the steel industry too, reliability is the watchword. Whether the motors drive pumps or power rolling mills, they must operate immediately. Modern production schedules can tolerate no delay. And here too, alert engineers are standardizing on DOLPH'S CHINALAK Black Baking Varnish for the insulation of motor windings. They have proven by actual experience that this remarkable black baking varnish definitely affords greater protection and insures reliable, trouble-free operation.

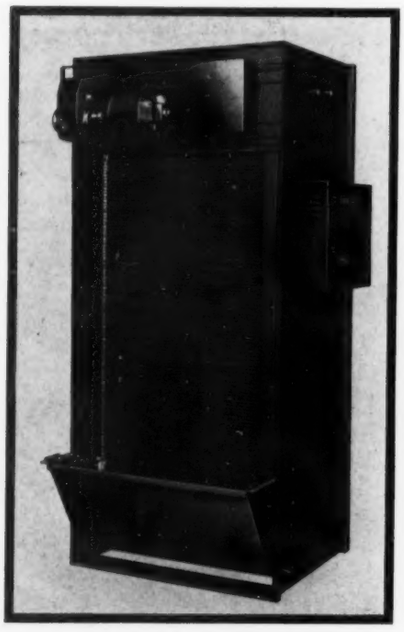
JOHN C. DOLPH CO.

Insulation Specialists

166A Emmett Street Newark, N. J.

DUAL METHOD FOR AIR CLEANING

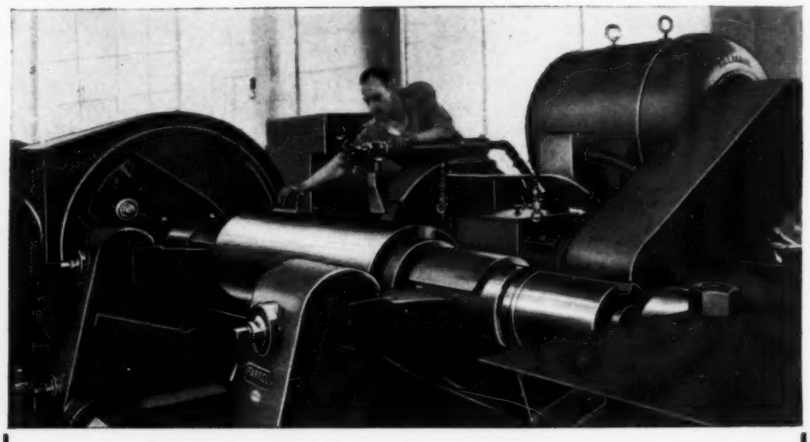
▲ The "Electro-Matic Air Filter" recently introduced by the American Air Filter Company, Inc., is an entirely new development in which electrical precipitation has been combined with automatic air filtration to obtain the combined advantages of these two



methods of cleaning air. Electrical precipitation has long been recognized as one of the most efficient methods of eliminating smoke and fine dust particles from the air, while the adhesive impingement principle as used in the viscous air filters, has definitely proved its effectiveness with ordinary atmospheric dust. These two methods combined in a single filter not only assure a uniformly high cleaning efficiency over practically the entire range of particle sizes, but offer other advantages which distinguish this development as an outstanding advancement in modern air cleaning.

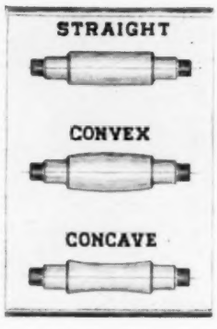
In operation the front curtain of the filter acts as a precleaner to remove the heavier dust particles and any insects, or scraps of material that might short circuit the ionizer of the collector plates in the rear curtain. Fine dust and smoke particles which escape the front curtain then pass through the ionizing unit in the center of the filter where they receive a definite electrical charge. Upon entering the electrostatic field of the rear curtain these ionized dust particles are attracted to the charged plates where they are held securely in the oil film on the plates until removed in the oil bath.

The filter curtain of the filter is of a new design, which provides the necessary electrical insulation of the plates and a means for charging or grounding alternate plates in certain sections of the curtain. It meets the additional requirement of reverse direction of rotation so that the accumulation of dust and dirt on the front curtain is carried directly down into the reservoir where it is removed by the cleansing action of the oil bath, leaving the rear curtain clean and freshly oiled at all times. The entire casing of the filter, as well as the front curtain, is thoroughly grounded.



FARREL ROLL GRINDERS

Permit Close Control of Roll Accuracy and Finish



In the Farrel Roll Grinder roll shape is automatically controlled. Straight, convex or concave contours are ground exactly symmetrical on both halves of the roll.

•

For full information send for copy of Bulletin No. 111.

Due to the automatic and semi-automatic features of the Farrel Heavy Duty Roll Grinder, roll accuracy and finish can be closely controlled to meet predetermined standards. Dependence on the operator's skill to produce rolls of close accuracy and fine finish is reduced to the minimum.

With Farrel Heavy Duty Roll Grinders, rolls of any material can be ground with extreme precision, and any finish can be obtained which is possible to secure with wheels now available. These grinders do heavy roughing or fine finishing equally well. They will grind straight, convex or concave contours to exact symmetry and accuracy, and produce a perfect surface free from marks of any kind.

This close control of roll accuracy and finish makes possible the production of rolled metal strip and sheet with better quality surface and more accurate gauge.

FARREL

FARREL-BIRMINGHAM COMPANY, Inc.
ANSONIA, CONN.
New York • Buffalo • Pittsburgh • Akron • Chicago • Los Angeles

—AND HE MARRIED THE BOSS'S DAUGHTER

JACK, the electrician, was never one to be satisfied with less than the best; that's why the boss's daughter is now Mrs. Jack. The same characteristic is probably behind his insistence upon Rockbestos, the wire with "Ten Tested Values," for circuits that were periodic trouble-makers because of breakdowns resulting from exposure to heat and moisture, oil, grease or corrosive fumes.

Rockbestos heat-resisting wires, cables and cords will reduce your maintenance expense and prove more economical in length of service, because they are made to stand up under operating conditions that are destructive to other wires. Their asbestos insulation doesn't dry out and crack under heat, or with age; neither does it rot, bloom or swell under the attack of oil, grease or corrosive fumes. In addition, it gives you the safety factor of a fireproof wire and the other extra advantages listed in the "Ten Tested Rockbestos Values."

If you want to save money and improve your service let us make recommendations and send samples, or, if you prefer, we'll have one of our engineers call on you. If you haven't one of our catalogs write for the new No. 10-E Handbook illustrating our line of standard constructions . . . Rockbestos Products Corporation, 921 Nicoll Street, New Haven, Connecticut.

TEN TESTED ROCKBESTOS VALUES

1. Heatproof
2. Fireproof
3. Permanent
4. Lower maintenance cost
5. Resists heat and vibration
6. Saves work
7. Oil and Greaseproof
8. High overload capacity
9. Permanently flexible
10. Greater carrying capacity

Also refer to Electrical World Buyer's Reference

ITEMS OF INTEREST

G. Cook Kimball was elected an executive vice-president of the United States Steel Corporation of Delaware, with headquarters at the Chicago executive offices at 208 South La Salle Street. For the past four years Mr. Kimball has been executive vice-president of the Carnegie-Illinois Steel Corporation with offices in Chicago, Illinois. Since 1901, he has been connected with United States Steel subsidiaries, beginning in the engineering department of the American Tin Plate Company a year after his graduation from Harvard University. From 1905 to 1931 he served as chief engineer of the American Sheet and Tin Plate Company, and in 1931 was elected vice-president and a director of the company. Mr. Kimball also is a director of the Carnegie-Illinois Steel Corporation, president of Illinois Steel Company, and president of the Gary Land Company.

G. COOK KIMBALL

Henry J. Mokate was appointed manager of the merchant products bureau, sheet division of Carnegie-Illinois Steel Corporation, Pittsburgh, Pennsylvania. The merchant products bureau, a newly created unit of the general sales department, will handle sheet sales to the jobbing trade and certain accounts for galvanized materials. Mr. Mokate, associated with subsidiary companies of United States Steel Corporation since 1920, has been manager of the secondary products division since its formation in June, 1938. He had previously served Carnegie-Illinois and the former American Sheet and Tin Plate Company at Chicago, Illinois, De Moines, Iowa, and Rockford, Illinois.

Charles Schramm has been appointed manager of the secondary products division, Carnegie-Illinois Steel Corporation, Pittsburgh, Pennsylvania. Mr. Schramm has been associated with subsidiary companies of the United States Steel Corporation at New York since 1902. He held various sales positions with the former American Sheet and Tin Plate Company, and has been a salesman at the New York offices of Carnegie-Illinois since 1936.

Peter J. Muller has been appointed group leader in charge of cost study in the industrial engineering department at the Gary Works, Carnegie-Illinois Steel Corporation, Gary, Indiana. Mr. Muller goes to Gary from the South Works of Carnegie-Illinois Steel Corporation, Chicago, Illinois. After serving in various capacities in the blast furnace department until 1937, he was made a junior industrial engineer. A year later he was appointed to the post of industrial engineer, the position he held until the present time.

Walter F. Munford was elected assistant to vice-president of operations at the American Steel and Wire Company's main offices in Cleveland, Ohio. Mr. Munford was born in Worcester, Massachusetts on June 8, 1900. He was educated in the Worcester schools and attended the Worcester Polytechnical Institute where he majored in mechanical engineering. Later, he marticulated at Massachusetts Institute of Technology where he majored in the same subject.

Mr. Munford's first position with the American Steel and Wire Company was during his summer vacation in 1919 when he worked as a die reamer at the company's North Works in Worcester, Massachusetts. After leaving school he became a helper in the open hearth department. Following this, came two other positions before he was made the superintendent of the open hearth in 1927. In 1930 he was transferred to Cleveland where he became superintendent of the open hearth at the company's Newburgh Works. Three years later, when this division was dismantled, he was transferred to the National Tube Company at Lorain, Ohio, as assistant superintendent of the steel works. Mr. Munford became assistant superintendent at the American Steel and Wire Company's Cuyahoga Works in Cleveland, Ohio, in 1934, and superintendent in January, 1937. His appointment as assistant to vice-president was made effective April 15, 1939.

WALTER F. MUNFORD

H. L. Jenter formerly assistant superintendent at the Cuyahoga Works of the American Steel and Wire Company, Cleveland, Ohio, was made general superintend-

ent of that plant, which includes the largest cold rolled strip plant in the world. Other appointments at the Cuyahoga Works of the American Steel and Wire Company are as follows:

A. G. Montgomery
is appointed superintendent of the hot mills;

V. H. Leichliter
becomes superintendent of the wire mill;

J. D. Baster
becomes superintendent of the cold rolled mills.

F. H. Cash
formerly superintendent of the Susquehanna Alexandria mines, Republic Steel Corporation, has been appointed general superintendent of the Republic Steel Corporation's Minnesota ore mines with headquarters at Hibbing, Minnesota. Mr. Cash has been with Republic Steel and its predecessor company for thirty years, having been with the maintenance of way department of the Frisco line prior to that time.

W. M. Webb
formerly superintendent of Penokee and Ironton mines of the Republic Steel Corporation, has been appointed general superintendent of Republic's Michigan mines with headquarters in Bessemer, Michigan. Mr. Webb has spent twenty-nine years with the Republic Iron and Steel Company and Republic Steel Corporation. He started in as mine captain, was promoted to safety inspector, and then to superintendent. Prior to his association with Republic he was with the Pittsburgh Iron Ore Company.

Owen Hollenbaugh
has been made blast furnace superintendent of the Alan Wood Steel Company, Conshohocken, Pennsylvania, succeeding C. E. Agnew who has resigned.

R. B. Mildon
vice-president of the Westinghouse Electric and Manufacturing Company, in charge of the East Pittsburgh, Pennsylvania, division moves to Pittsburgh headquarters of the company to assume special sales assignments. Mr. Mildon went to Pittsburgh in April, 1938 from Philadelphia where he had been in charge of the South Philadelphia Steam and Stoker division. He has been associated with the Westinghouse Company since 1906, and has been a vice-president since 1934.

A. C. Streamer
was appointed general manager of the East Pittsburgh division of the Westinghouse Electric and Manufacturing Company. Mr. Streamer, who has been manager of the switchgear division, started in the East Pittsburgh Works in 1907 after graduating as an electrical engineer from Colorado State University. After completing the apprentice engineering course, he was assigned to the switchboard engineering department. In 1931 he was made manager of the diversified products department, and continued in executive positions that led to his appointment as manager of the switchgear division when it was formed. This division is among the major manufacturing activities at the the East Pittsburgh Works.

M. W. Smith
formerly manager of engineering of the Westinghouse Electric and Manufacturing Company, has been elected a vice-president of the company. Mr. Smith, who will direct all the company's engineering activities, has been associated with Westinghouse since the day he left college in 1915. He will maintain headquarters at Pittsburgh, Pennsylvania.

J. E. Freemann
was appointed district manager in the Philadelphia territory for the Baker Industrial Truck Division of the Baker-Raulang Company. Mr. Freemann, who will be assisted by Emory N. Mumma, has his headquarters at 709 Arch Street, Philadelphia, Pennsylvania.

T. A. Kenny
has been appointed as exclusive representative of the Esterline-Angus Company, Inc., in the Pittsburgh territory. Mr. Kenny succeeds H. L. Hildenbrand who has been appointed representative for this company in the New York Metropolitan area.

V. H. Lawrence
formerly metallurgical engineer of the Alan Wood Steel Company, Conshohocken, Pennsylvania, has been made assistant to the vice-president.

Other appointments at the Conshohocken plant of the Alan Wood Steel Company are as follows:

L. E. Ekholm
succeeds V. H. Lawrence as metallurgical engineer;

W. A. Ericksen
has been made open hearth superintendent;

A. F. Franz
was appointed superintendent of the steel division;

I. F. Wolfgram
was made superintendent of the coke plant and blast furnaces;

P. C. Mayfield
replaces I. F. Wolfgram as coke plant superintendent;

W. B. Haus
is now blooming mill superintendent.

G. T. Luippold
has been appointed Los Angeles district representative for the Foote Brothers Gear and Machine Corporation. Mr. Luippold will maintain his headquarters at 1115 South Hope Street, Los Angeles, California.

Obituaries

Albert Gould Davis
67, retired vice-president in charge of patents of the General Electric Company recently died. Mr. Davis was born in Brooklyn in 1871. He was graduated from Massachusetts Institute of Technology in 1893. In December 1897, after completing a course at the National Law School, Mr. Davis became manager of the General Electric Company's patent department. He was appointed vice-president of the company on November 21, 1919, retiring May 1, 1933.

John F. Regan, Jr.
formerly superintendent of the coke plant of the Youngstown Sheet and Tube Company, Campbell, Ohio, recently died in his fifty-fifth year. Mr. Regan, who was born in Terre Haute, Indiana, was graduated from Rose Polytechnic Institute. He had been employed by the Youngstown Sheet and Tube Company for nearly thirty years.

Elmer F. Obley
formerly superintendent of industrial relations at the Clairton Works of the Carnegie-Illinois Steel Corporation, Clairton, Pennsylvania, died on May 6.

For Rough and Tumble Service!

¶ Where there's need for Electrical Control Apparatus that stands the rigors of modern speedy production, there you'll find "3C" controls.

¶ Typical of these brawny "3C" devices is the Bulletin 101, Type RD, Heavy Duty Mill Master Switch.

¶ A quick examination of this Switch shows why it meets with instant approval, and renders yeoman service where the going is heavy.

¶ It stands up, not only because of advanced engineering design developed through years of practical experience, but also because it has "wear-resistance" built into it.

¶ Strong cast iron housing • • • liberal mounting feet to insure non-rocking installation • • • a brute of a handle that invites you to slam it back and forth • • • needle roller bearings • • • Bakelite cams • • • oversize shaft • • • Double break silver contacts • • • contact fingers interchangeable with those in Bulletin 101 Type F. R. Foot Switch, Bulletin 102 Type C. L. Cam Limit Switch and Bulletin 102 Type H. L. Hatchway Limit Switch • • • no relative motion between lever and shaft • • • square shaft snugly fitting square hole in cams eliminates cam movement on shaft • • • entire cam and shaft assembly easily removed with no disturbance to contact finger assembly.

A folder fully descriptive of this switch is yours for the asking.

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THE CLARK CONTROLLER CO.

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